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ORIGINAL PAPER

# Assessment of the adaptive capacity of Morada Nova ewes with different coat coloration

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## Abstract

Coat color is a factor affecting heat tolerance in tropical ruminant and a particular coat color can determine which is more resilient to environmental changes. The aim of this study was to measure the level of adaptation of Morada Nova sheep with different coat color by using an Adaptability Index (AI). Adult ewes were used, including two different coat colors of Morada Nova sheep (red and white) with mean of body weight of 28.02 ± 5.70 kg and 31.47 ± 3.41 kg, respectively. Physiology parameters, hematology, electrolytes, acid–base status, mineral, renal functions, metabolites, enzymes, and proteins were measured. AI was designed using a multivariate approach (principal component analysis) to "weigh" the influence of each variable in the animal responses. The variables more important for adaptive aspects of Red Morada Nova were: haematology, electrolytes and acid–base status. The hemoglobin (HG), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), sodium ($Na^+$), oxygen pressure ($PO_2$), glucose (GLU) and albumin (ALB) were significantly higher in Red Morada Nova sheep and hydrogen carbonate ($HCO^3$), base excess (BE), total carbon dioxide concentration ($TCO_2$) and URE were significantly higher in the white phenotype. The variables more important for adaptive aspects of White Morada Nova sheep were: ($K^+$), total protein (TP), $PO_2$, HG, cholesterol (CHO), rectal temperature (RT) and glucose (GLU). Both phenotypes showed a high adaptation level, however, a higher value was generated for the Red Morada Nova sheep (81.97). This study concludes that both phenotypes of the Morada Nova sheep breed are well adapted to the climatic condition of the Brazilian tropical region using different adaptive mechanisms.

**Keywords** Acid–base status · Hair sheep · Native sheep · Principal component analysis · Tropical climate

## Introduction

Modern livestock farming seeks animals that are better adapted to environmental conditions. Locally adapted animals incorporate traits that support sustainable production systems. Animal genetic resources are increasingly selected for traits that bring economic and/or environmental benefits, such as reduced water use (Araújo et al. 2019; Paz et al 2018; Freitas et al. 2021), feed, productive and reproductive efficiency (Pinheiro et al. 2020; Freitas et al. 2020; Gurgeira et al. 2022), resistance to illnesses such as gastrointestinal parasites (Toscano et al. 2019; Freitas et al. 2022), carcass characteristics (Issakowicz et al. 2018; Geraldo et al. 2020 and thermal tolerance (Ferreira et al. 2020).

Sheep farming is performed almost throughout the world and is an option for smallholders in the face of climatic problems such as global warming. The latter stimulates animal selection and the use of locally adapted breeds considered

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resilient to climate change associated with the increased environmental temperature. The Morada Nova sheep breed is known for traits such as production of meat and hides, high prolificacy and parasite resistance and (David et al. 2018), and especially high resistance in tropical environments (Leite et al. 2018[a]; Ferreira et al. 2021; Façanha et al. 2021). Therefore, this breed is considered useful for industrial breeding programs with breeds having higher productive (David et al. 2018).

Coat color is a factor affecting heat tolerance in tropical sheep (McManus et al. 2011; Leite et al. 2020; Castro et al. 2020). A particular coat color can determine which is more resilient to environmental changes (Façanha et al. 2021; Ferreira et al. 2021). However, in populations of Morada Nova, where the effective number of animals is reduced and there is a constant effort to increase genetic variability (Nunes et al. 2022a, b), it is essential to incorporate more animals regardless of coat color to increase the effective number of animals (Muniz et al. 2016).

The adaptive mechanisms of each species, breed, or genetic group are often particular and possibly change throughout the animals' lives, aiming at the maintenance of homeostasis. When homeostasis breaks down in the body, there are four mechanisms that can be activated in response to stress: behavior, immunity, and autonomic and, neuroendocrine response and immune responses (Eloy 2007). These actions occur according to the degree of impact of the stressor, which can trigger a drop in immunity, productivity and affect the welfare of production animals. Heat is one of the main causes of stress in Brazilian animal production systems, and can cause an imbalance in body temperature, respiratory cycles, and metabolic changes serum concentrations and hematology in sheep (Arfuso et al. 2021; Façanha et al. 2021). Vasconcelos et al. (2020) implemented an Adaptability Index (AI) for dairy cows using thermoregulation, hematology and serum biochemistry parameters, which may answer the question of the present study given the multivariate responses of animals to stress (McManus et al. 2022). Therefore, the aim of this study was to measure the level of adaptation of Morada Nova sheep with different coat color by using AI.

## Material and methods

### Area characterization, animals and experimental design

The research was carried out in a herd of the Federal Rural University of the Semi-arid Region (UFERSA)/Morada Nova Sheep Conservation Center in the northeast region of Brazil (Geographic coordinate: 05° 12′ 45" N, 37° 19'; Height: 20 m a.s.l.). According to the Koppen classification (Alvares et al. 2013), the climate is type A tropical, with presence of two seasons during the year, where rainy period (January to June) and a dry period (July to December). The annual average temperature and relative humidity in year of the experiment were between 27–30 °C and 40–80%, respectively.

10,920 information of ten adult ewes (5 Red Morada Nova sheep and 5 White Morada Nova sheep) were used, with aged 3 to 5 years, non-pregnant and healthy according to clinical examination, with mean weights of $28.02 \pm 5.70$ kg and $31.47 \pm 3.41$ kg, respectively, and with body condition scores classifications between 3 to 4 (Machado et al. 2008). The animals were kept in a sheepfold with access to feed (Bermuda grass hay, *Cynodon dactylon* Pers.), water ad libitum and a mineral mixture and vitamin complex. The number of animals is justified by the difficulty of measuring blood gases. The animals were evaluated on different days (6 measurements per animal each hour of the day: 0600 h, 1300 h and 1800 h × 7 weeks × 2 periods: dry and rainy). Given the number of times throughout the day and different periods, we assumed that the adaptive profile was well characterized. Twenty-five variables related to adaptive aspects (Physiology parameters; Hematology, Electrolytes; Acid–base status; Mineral; Renal functions; Metabolites; Enzymes; Proteins) were used, totaling a database with 4,500 pieces of information.

### Thermal environmental characterization

The air temperature during the experimental phase was around 28 °C with maximum of 36 °C in the hottest hours and minimum of 20 °C in the coldest hours, and the relative humidity near 61% (maximum = 84.5%; minimum = 35.8%), both recorded by a digital thermocouple (Fig. 1). Radiant heat load between 400 and 900 W $m^{-2}$, estimated according to Silva (2008).

### Measurement of physiological parameters

The rectal temperature (RT, °C) was measured with a digital thermometer (Omron Flex Temp Digital thermometer, China) inserted into the animal's rectum. This equipment has scale from 32 to 43.9 °C and an accuracy of ± 0.1 °C. The respiratory rate (RR, breaths $min^{-1}$) was recorded through a stethoscope (Pro-Lite, Macrosul, Brazil) by a trained person after the animal calms down. The animals are used to the daily handling routine.

### Blood examinations – haematology and serum concentrations (electrolytes, acid–base status, mineral, renal functions, metabolites, enzymes and proteins)

Two blood samples of 5 mL each were collected from the same animal from the jugular vein. The tubes for

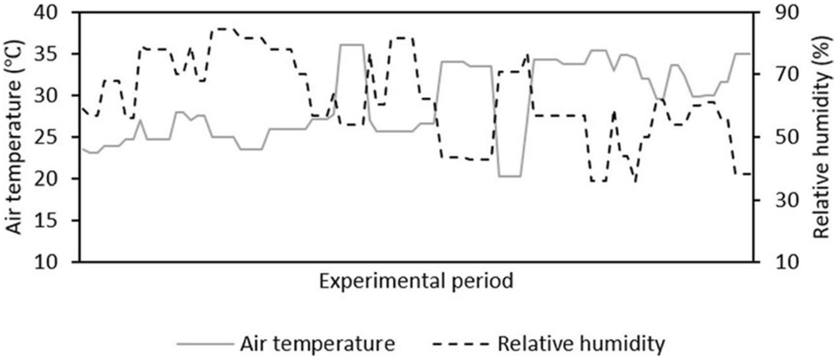


**Fig. 1** Air temperature and relative humidity for the experimental period

hematological examinations have Vacutainer system with ethylenediaminetetraacetate anion (EDTA) and SST II gel tubes for serum biochemical analyses. The first sample was used for hematological examinations: haemoglobin (HG, g $dL^{-1}$), packed cell volume (PCV, %), red blood cells (RBC, $\times 10^6$ µL), mean corpuscular volume (MCV, fL), mean corpuscular haemoglobin (MCH, pg) and mean corpuscular haemoglobin concentration (MCHC, g $dL^{-1}$) using an automatic blood analyzer (Labtest Diagnostica SA, Lagoa Santa, Minas Gerais, Brasil). The second sample was used for serum biochemical analyses. The tubes containing blood samples were centrifuged and frozen at -20 °C until processing; specific commercial kits (VIDA Biotecnologia, Belo Horizonte, Minas Gerais, Brasil) to determine serum levels of sodium ($Na^+$, mmol $L^{-1}$), potassium ($K^+$, mmol $L^{-1}$), calcium ($Ca^{+2}$, mmol $L^{-1}$), urea (URE, mg $dL^{-1}$), creatinine (CRE, mg $dL^{-1}$), cholesterol (CHO, mg $dL^{-1}$), glucose (GLU, mg $dL^{-1}$), alanine aminotransferase (ALT, units $L^{-1}$), aspartate aminotransferase (AST, units $L^{-1}$), protein (TP, g $dL^{-1}$) and albumin (ALB, g $dL^{-1}$)) using an automatic serum biochemistry analyzer, immediately after blood collection..

Arterial blood samples were collected from ear vessels with heparinized syringes to determine acid–base balance, electrolytic and mineral parameters. The hydrogen potential (pH), partial pressure of carbon dioxide ($PCO_2$, mmol $L^{-1}$), oxygen pressure ($PO_2$, mmol $L^{-1}$), hydrogen carbonate ($HCO_3$, mmol $L^{-1}$), base excess (BE, mmol $L^{-1}$) and total carbon dioxide concentration ($TCO_2$, mmol $L^{-1}$) were recorded immediately after collection evaluated using a portable analyzer (Abbott, Illinois, USA), using an EG7 + cartridge. The apparatus was calibrated daily before each evaluation using a simulator (i-STAT 1 Electronic Simulator, Chicago, Illinois, USA).

### Statistical procedures and adaptability index calculation

The database was tested to verify for the presence of outliers, linearity and homoscedasticity before performing the subsequent statistical analyses. The AI calculation followed the methodological path of Vasconcelos et al. (2020): 1st Weighting of eigenvalues and eigenvectors; 2nd Weighting of each variable in database; 3rd Evaluated each mean of each variable and determine a score; 4th Obtaining AI. The Cronbach's alpha was estimated to test the reliability of the variables which made up each factor. Bartlett's sphericity test, Kaiser–Meyer–Olkin (KMO) criteria and presuppositions were checked for the reliability of the analysis and to confirm the sampling accuracy.

After determining the weight of each variable within its respective CP (Table 1), the means of each variable received a score ($S_P$) of 0 = out of reference rages, 5 = small divergence for reference values or 10 = within reference ranges (Radostits et al. 2000; Reece and Swenson 2004; Ortolani 2018) described together with the means of each variable in Table 2. These $S_P$s were multiplied by the weighting eigenvectors ($W_V$). The indices were generated between 0.0 and 100 for the two studied Morada Nova sheep of different coat colors. This measure was used to characterize the Adaptability Index on a zero (0 = poorly adapted) to hundred scale (100 = very adapted). The effect of the hair colour (Red and White) was considered a fixed effect. Data were submitted to an analysis of variance (ANOVA), and the means compared using the parametric test (Tukey test) and a significantly level of 5%. The statistical analyzes were performed in the Statistical Package for the Social Sciences (SPSS), version 20, 2010 (SPSS Inc., Chicago, Illinois, USA).

## Results and discussion

A multivariate approach describes a condition at the global level and can improve understanding and help define the adaptive profile using different variables and effects. The PCA produced 25 factors (axis), and a scree plot was developed according to Cattell (1966) criteria using 10 PC (principal components) (86.74%) for Red Morada Nova sheep and 8 PC (75.21%) for White Morada Nova sheep to create AI, according to Kaiser (1960) of maintaining eigenvalues greater than 1 (Fig. 2). In classificatory order, of the more

**Table 1** Weighting eigenvectors of the principal components retained of each adaptive variable of Morada Nova sheep with different coat colors

| Variables | Red Morada Nova sheep | | | | | | | | | | | White Morada Nova sheep | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | $W_V$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | $W_V$ |
| RT $^{€}$ | 0.06 | 0.09 | -0.10 | -0.02 | 0.05 | 0.87 | -0.02 | 0.02 | 0.04 | 0.08 | 0.407 | 0.12 | 0.00 | -0.01 | -0.01 | 0.88 | -0.04 | 0.08 | 0.09 | 0.420 |
| RR $^{€}$ | 0.16 | -0.04 | 0.05 | -0.01 | -0.02 | 0.86 | -0.02 | -0.12 | -0.02 | -0.04 | 0.401 | -0.01 | -0.04 | -0.02 | 0.00 | 0.87 | 0.00 | -0.04 | 0.02 | 0.397 |
| HG $^{\beta}$ | -0.05 | 0.94 | 0.25 | -0.04 | 0.17 | -0.01 | 0.02 | -0.05 | 0.08 | -0.01 | 0.436 | 0.96 | -0.17 | -0.02 | -0.07 | 0.02 | 0.07 | 0.07 | 0.00 | 0.424 |
| PCV $^{\beta}$ | -0.08 | 0.88 | 0.43 | -0.01 | 0.04 | 0.04 | -0.03 | -0.01 | 0.09 | 0.03 | 0.437 | 0.90 | -0.19 | -0.09 | -0.03 | 0.06 | 0.04 | 0.21 | -0.08 | 0.418 |
| RBC $^{\beta}$ | -0.12 | 0.93 | -0.23 | -0.04 | 0.14 | 0.07 | 0.06 | 0.00 | 0.06 | 0.04 | 0.412 | 0.91 | -0.18 | -0.01 | -0.06 | 0.05 | -0.25 | 0.12 | -0.02 | 0.409 |
| MCV $^{\beta}$ | 0.03 | 0.11 | 0.97 | 0.05 | -0.10 | -0.02 | -0.10 | 0.00 | 0.05 | 0.00 | 0.415 | -0.37 | 0.05 | -0.20 | 0.08 | 0.03 | 0.81 | 0.18 | -0.12 | 0.360 |
| MCH $^{\beta}$ | 0.10 | 0.32 | 0.85 | 0.01 | 0.14 | -0.11 | -0.05 | -0.10 | 0.05 | -0.09 | 0.428 | 0.17 | 0.01 | -0.04 | 0.01 | -0.06 | 0.93 | -0.15 | 0.09 | 0.404 |
| MCHC $^{\beta}$ | 0.11 | 0.31 | -0.58 | -0.11 | 0.46 | -0.15 | 0.14 | -0.14 | -0.02 | -0.14 | 0.365 | 0.66 | -0.03 | 0.23 | -0.14 | -0.12 | 0.08 | -0.41 | 0.25 | 0.408 |
| Na$^{+}$ $^{\alpha}$ | -0.03 | 0.34 | 0.12 | -0.18 | -0.09 | 0.35 | -0.03 | 0.15 | 0.58 | -0.01 | 0.410 | 0.36 | -0.45 | 0.12 | -0.17 | 0.27 | 0.26 | -0.06 | -0.17 | 0.369 |
| K$^{+}$ $^{\alpha}$ | 0.00 | 0.04 | -0.03 | -0.01 | 0.02 | -0.01 | -0.05 | 0.01 | 0.11 | 0.93 | 0.389 | 0.06 | 0.08 | 0.63 | 0.10 | 0.07 | 0.10 | 0.28 | 0.17 | 0.436 |
| Blood pH $^{£}$ | 0.64 | 0.00 | -0.11 | 0.06 | -0.04 | 0.33 | 0.03 | -0.60 | 0.09 | -0.08 | 0.397 | -0.15 | 0.16 | 0.07 | -0.05 | 0.31 | 0.02 | 0.03 | -0.19 | 0.372 |
| $PCO_2$ $^{£}$ | 0.32 | 0.00 | 0.11 | -0.17 | 0.01 | -0.26 | 0.00 | 0.82 | -0.11 | 0.08 | 0.400 | -0.09 | 0.56 | -0.03 | -0.06 | -0.63 | 0.05 | 0.17 | 0.16 | 0.366 |
| $PO_2$ $^{£}$ | -0.20 | 0.04 | 0.02 | 0.47 | 0.28 | 0.28 | 0.12 | -0.28 | -0.01 | 0.45 | 0.404 | 0.10 | -0.24 | 0.41 | 0.52 | 0.36 | 0.03 | 0.10 | -0.03 | 0.427 |
| $HCO_3$ $^{£}$ | 0.95 | -0.06 | 0.03 | -0.13 | -0.04 | 0.03 | -0.01 | 0.20 | -0.03 | 0.00 | 0.426 | -0.16 | 0.95 | -0.06 | 0.01 | -0.02 | 0.02 | -0.05 | 0.01 | 0.413 |
| BE $^{£}$ | 0.97 | -0.07 | 0.00 | -0.08 | -0.05 | 0.16 | 0.02 | 0.00 | 0.01 | -0.02 | 0.427 | -0.13 | 0.93 | -0.06 | 0.04 | 0.18 | 0.04 | -0.10 | -0.07 | 0.424 |
| $TCO_2$ $^{£}$ | 0.93 | -0.09 | 0.06 | -0.13 | -0.03 | -0.01 | 0.00 | 0.24 | -0.03 | -0.02 | 0.424 | -0.14 | 0.96 | -0.05 | -0.01 | -0.11 | 0.03 | -0.01 | 0.02 | 0.412 |
| $Ca^{+2}$ $^{¥}$ | 0.22 | -0.06 | -0.24 | 0.03 | 0.06 | 0.24 | 0.13 | 0.65 | 0.12 | -0.15 | 0.403 | -0.03 | 0.04 | -0.01 | -0.03 | -0.02 | 0.01 | 0.02 | 0.93 | 0.378 |
| URE $^{\kappa}$ | 0.01 | -0.04 | -0.03 | -0.17 | -0.16 | 0.08 | -0.04 | 0.09 | -0.87 | -0.13 | 0.323 | -0.12 | 0.10 | 0.09 | 0.75 | -0.07 | -0.14 | -0.27 | -0.05 | 0.388 |
| CRE $^{\kappa}$ | 0.13 | -0.14 | -0.02 | -0.01 | -0.88 | -0.01 | -0.18 | -0.03 | -0.15 | -0.15 | 0.309 | 0.02 | 0.16 | -0.84 | 0.25 | 0.02 | -0.02 | 0.15 | 0.06 | 0.337 |
| CHO $^{\lambda}$ | 0.02 | -0.09 | -0.05 | 0.04 | -0.01 | -0.01 | 0.93 | 0.09 | -0.06 | 0.01 | 0.395 | -0.06 | 0.02 | 0.60 | 0.56 | -0.05 | 0.19 | -0.29 | -0.02 | 0.424 |
| GLU $^{\lambda}$ | -0.11 | 0.10 | 0.09 | 0.83 | 0.07 | -0.08 | -0.14 | -0.01 | 0.22 | -0.20 | 0.400 | 0.33 | -0.12 | 0.34 | 0.12 | -0.03 | -0.05 | 0.67 | 0.03 | 0.420 |
| ALT $^{\sigma}$ | -0.08 | 0.05 | -0.20 | 0.31 | 0.55 | 0.09 | 0.45 | 0.05 | -0.30 | 0.01 | 0.403 | -0.12 | 0.05 | 0.61 | 0.19 | -0.04 | -0.32 | 0.00 | -0.12 | 0.384 |
| AST $^{\sigma}$ | 0.02 | 0.17 | -0.12 | -0.06 | 0.32 | -0.04 | 0.83 | -0.04 | 0.15 | -0.06 | 0.411 | 0.08 | -0.16 | 0.74 | 0.05 | 0.06 | -0.20 | 0.18 | -0.01 | 0.402 |
| TP $^{\tau}$ | -0.15 | -0.16 | 0.03 | 0.90 | -0.13 | 0.00 | 0.12 | -0.05 | -0.08 | 0.14 | 0.385 | 0.03 | 0.00 | 0.09 | 0.90 | -0.03 | 0.08 | 0.27 | 0.02 | 0.430 |
| ALB $^{\tau}$ | 0.04 | 0.25 | 0.01 | -0.58 | 0.69 | 0.06 | -0.04 | 0.12 | 0.13 | -0.14 | 0.389 | 0.34 | -0.05 | 0.33 | -0.73 | -0.01 | -0.07 | -0.23 | -0.03 | 0.348 |
| Variance % | 13.80 | 12.16 | 9.98 | 9.25 | 8.39 | 8.06 | 7.61 | 6.90 | 5.53 | 5.06 | | 14.77 | 13.86 | 11.69 | 10.77 | 9.26 | 7.55 | 4.85 | 4.45 | |
| Cumulative % | 13.80 | 25.96 | 35.94 | 45.19 | 53.58 | 61.64 | 69.25 | 76.16 | 81.69 | 86.74 | | 14.77 | 28.63 | 40.32 | 51.09 | 60.35 | 67.90 | 72.75 | 77.20 | |

Wv: Weighting eigenvectors; Variable type: $^{€}$Physiological parameters; $^{\beta}$Hematology; $^{\alpha}$Electrolytes; $^{£}$Acid–base status; $^{¥}$Mineral; $^{\kappa}$Renal functions; $^{\lambda}$Metabolites; $^{\sigma}$Enzymes; $^{\tau}$Proteins

**Table 2** Mean and standard deviation (± SD) followed score ($S_P$) for each adaptive variable of Morada Nova sheep with different coat colors followed by reference values (RV) for *Ovis aries*

| Variables | Units | Red Morada Nova sheep |  | White Morada Nova sheep |  | RV |
|---|---|---|---|---|---|---|
|  |  | µ ± SD | $S_P$ | µ ± SD | $S_P$ |  |
| RT $^{€}$ | °C | 38.78 ± 0.75 | 10 | 38.79 ± 1.01 | 10 | 38.3 – 39.9 $^{2}$ |
| RR $^{€}$ | breaths min$^{-1}$ | 63.68 ± 59.27 | 0 | 67.78 ± 60.82 | 0 | 20.0 – 34.0 $^{2}$ |
| HG $^{\beta}$ | g dL$^{-1}$ | 11.01 $^{a}$ ± 1.70 | 10 | 10.57 $^{b}$ ± 1.62 | 10 | 9.0 – 15.0 $^{1}$ |
| PCV $^{\beta}$ | % | 28.72 ± 4.22 | 10 | 28.18 ± 3.71 | 10 | 27.0 – 45.0 $^{1}$ |
| RBC $^{\beta}$ | × 10$^{6}$ µL | 7.60 ± 0.97 | 10 | 7.48 ± 1.13 | 10 | 9.0 – 15.0 $^{1}$ |
| MCV $^{\beta}$ | fL | 37.89 ± 3.43 | 10 | 37.76 ± 2.10 | 10 | 28.0 – 40.0 $^{1}$ |
| MCH $^{\beta}$ | pg | 14.47 $^{a}$ ± 1.05 | 5 | 14.11 $^{b}$ ± 0.72 | 5 | 8.0 – 12.0 $^{1}$ |
| MCHC $^{\beta}$ | g dL$^{-1}$ | 38.34 $^{a}$ ± 1.69 | 5 | 37.43 $^{b}$ ± 1.57 | 5 | 31.0 – 34.0 $^{1}$ |
| Na$^{+}$ $^{\alpha}$ | mmol L$^{-1}$ | 147.44 $^{a}$ ± 2.90 | 5 | 146.77 $^{b}$ ± 2.37 | 5 | 145 – 152 $^{1}$ |
| K$^{+}$ $^{\alpha}$ | mmol L$^{-1}$ | 4.32 ± 3.25 | 10 | 4.11 ± 0.51 | 10 | 3.9 – 5.4 $^{1}$ |
| Blood pH $^{£}$ | - | 7.41 ± 0.05 | 10 | 7.40 ± 0.31 | 10 | 7.28 – 7.42 $^{3}$ |
| $PCO_2$ $^{£}$ | mmol L$^{-1}$ | 36.54 ± 4.52 | 10 | 36.65 ± 5.69 | 10 | 34 – 45 $^{3}$ |
| $PO_2$ $^{£}$ | mmol L$^{-1}$ | 47.91 $^{a}$ ± 16.99 | 10 | 42.77 $^{b}$ ± 18.99 | 10 | 83 – 95 $^{3}$ |
| $HCO_3$ $^{£}$ | mmol L$^{-1}$ | 22.59 $^{b}$ ± 3.05 | 10 | 23.49 $^{a}$ ± 3.33 | 10 | 19 – 25 $^{3}$ |
| BE $^{£}$ | mmol L$^{-1}$ | -1.73 $^{b}$ ± 3.57 | 10 | -0.78 $^{a}$ ± 3.89 | 10 | -4.0 – 2.0 $^{3}$ |
| $TCO_2$ $^{£}$ | mmol L$^{-1}$ | 23.71 $^{b}$ ± 3.19 | 10 | 24.42 $^{a}$ ± 3.46 | 10 | 19 – 26 $^{3}$ |
| Ca$^{+2}$ $^{¥}$ | mmol L$^{-1}$ | 0.87 ± 0.21 | 0 | 0.90 ± 0.73 | 0 | 2.88 – 3.20 $^{1}$ |
| URE $^{\kappa}$ | mg dL$^{-1}$ | 34.50 $^{b}$ ± 9.20 | 10 | 43.77 $^{a}$ ± 13.00 | 5 | 10 – 35 $^{1}$ |
| CRE $^{\kappa}$ | mg dL$^{-1}$ | 0.79 ± 0.31 | 10 | 0.75 ± 0.29 | 10 | 1.2 – 1.9 $^{1}$ |
| CHO $^{\lambda}$ | mg dL$^{-1}$ | 65.57 ± 15.68 | 10 | 65.63 ± 12.54 | 10 | 43 – 103 $^{1}$ |
| GLU $^{\lambda}$ | mg dL$^{-1}$ | 55.73 $^{a}$ ± 7.37 | 10 | 48.07 $^{b}$ ± 10.07 | 5 | 50 – 80 $^{1}$ |
| ALT $^{\sigma}$ | units L$^{-1}$ | 21.90 ± 5.37 | 5 | 23.05 ± 3.64 | 10 | 22 – 38 $^{1}$ |
| AST $^{\sigma}$ | units L$^{-1}$ | 115.37 ± 45.70 | 10 | 108.00 ± 25.04 | 10 | 60 – 280 $^{1}$ |
| TP $^{\tau}$ | mg dL$^{-1}$ | 6.41 ± 1.40 | 10 | 6.29 ± 1.29 | 10 | 6 – 7.9 $^{1}$ |
| ALB $^{\tau}$ | mg dL$^{-1}$ | 3.94 $^{a}$ ± 0.94 | 5 | 3.60 $^{b}$ ± 0.93 | 5 | 2.4 – 3 $^{1}$ |

$^{ab}$Different letters on the same line indicate significant difference by the Tukey test with 5% probability

Variable type: $^{€}$Physiological parameters; $^{\beta}$Hematology; $^{\alpha}$Electrolytes; $^{£}$Acid–base status; $^{¥}$Mineral; $^{\kappa}$Renal functions; $^{\lambda}$Metabolites; $^{\sigma}$Enzymes; $^{\tau}$Proteins

*RT* rectal temperature, *RR* respiratory rate, *HG* haemoglobin, *PCV* packed cell volume, *RBC* red blood cells, *MCV* mean corpuscular volume, *MCH* mean corpuscular haemoglobin, *MCHC* mean corpuscular haemoglobin concentration, *Na*$^{+}$ sodium, *K*$^{+}$ potassium, *pH* hydrogen potential, $PCO_2$ partial pressure of carbon dioxide, $PO_2$ oxygen pressure, $HCO_3$ hydrogen carbonate, *BE* base excess, $TCO_2$ total carbon dioxide concentration, *Ca*$^{+2}$ calcium, *URE* urea, *CRE* creatinine, *CHO* cholesterol; *GLU* glucose, *ALT* alanine aminotransferase, *AST* aspartate aminotransferase, *TP* total protein, *ALB* albumin

RV: $^{1}$Radostits et al. (2000); $^{2}$Reece and Swenson (2004); $^{3}$Ortolani (2018)

important to less important variables according to adaptive aspects of Red Morada Nova sheep were: PCV, HG, MCH, BE, $HCO_3$, $TCO_2$, MCV, RBC, AST, Na$^{+}$, RT, $PO_2$, Ca$^{+2}$, ALT, RR, $PCO_2$, GLU, blood pH, CHO, K$^{+}$, ALB, TP, MCHC, URE and CRE; and for White Morada Nova sheep were: K$^{+}$, TP, $PO_2$, HG, BE, CHO, RT, GLU, PCV, $HCO_3$, $TCO_2$, RBC, MCHC, MCH, AST, RR, URE, ALT, Ca$^{+2}$, blood pH, Na$^{+}$, $PCO_2$, MCV, ALB and CRE.

The HG, MCH, MCHC, Na$^{+}$, $PO_2$, GLU and ALB were significantly ($P < 0.05$) higher in Red Morada Nova sheep and $HCO_3$, BE, $TCO_2$ and URE were significantly ($P < 0.05$) higher in the white phenotype. Table 2 presents the overall averages of all variables measured in Morada Nova sheep associated with the reference values for the *Ovis aries*, and 72% of the adaptive variables of Red Morada Nova sheep and 68% of the adaptive variables of White Morada Nova sheep were within the reference values. The RR and Ca$^{+2}$ were outside the reference values for both phenotypes. For Red Morada Nova sheep, the MCH, MCHC, Na$^{+}$, ALT and ALB variables were slightly outside the reference values for sheep, while in White Morada Nova sheep the variables that were slightly out of the normal range were MCH, MCHC, Na$^{+}$, URE, GLU and ALB. It is expected that some of the variables studied would not fall within the reference values created from a standardized *Ovis aries* population even though the animals used were deemed healthy, and, mainly, because of the reference values for the species to be from North American and European animals, with the exception

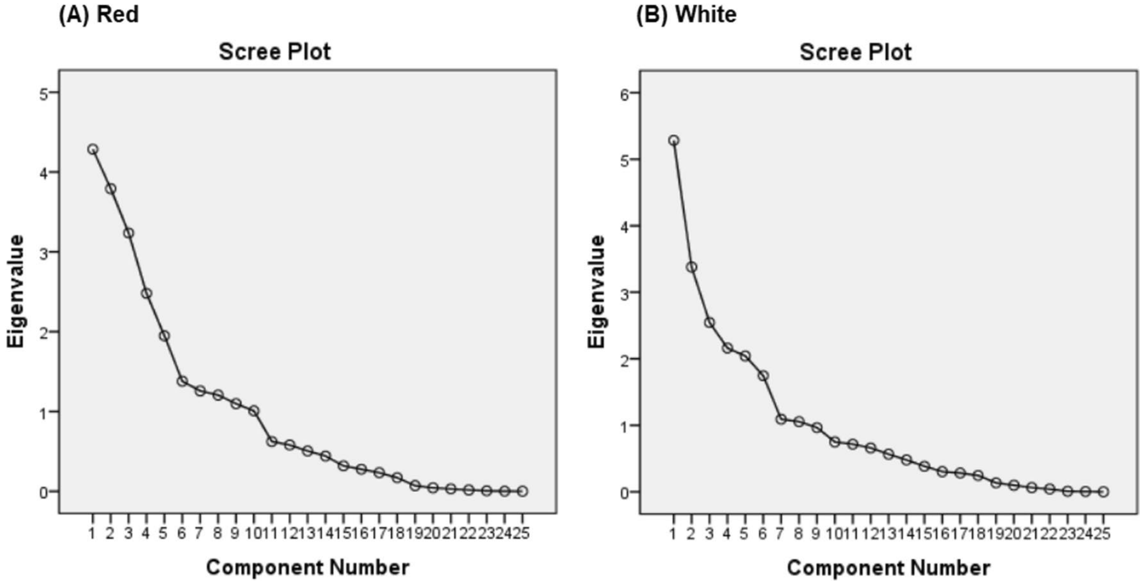
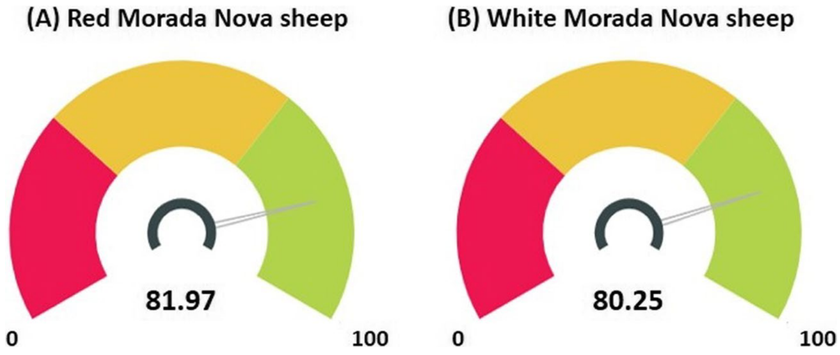


**Fig. 2** Scree plot of the eigenvalues corresponding the principal components analysis of adaptive aspects Morada Nova sheep with different coat colors. **A** Red Morada Nova sheep; **B** White Morada Nova sheep

of references related to acid–base balance (Ortolani 2018) which are from animals raised under Brazilian conditions. Although Carlos et al. (2015) did not identify significant variations between the reference values for *Ovis aries* and Morada Nova sheep, they discussed the need for comparison with reference values appropriate to the region and the particular population. Seixas et al. (2021) found differences between Brazilian sheep for overall reference values. According to David et al. (2012), there is a scarcity of hematological references for different sheep breeds, especially when it comes to native breeds. There is difficulty in creating complete comparison taking into account many variables and variation effects. However, the references used in our study (Radostits et al. 2000; Reece and Swenson 2004; Ortolani 2018) have shown good acceptance for evaluating the Morada Nova breed sheep population until specific references are created for the breed.

The big question of this study is to identify if there are better adaptive attributes as a function of different phenotypes of the Morada Nova sheep breed, using a multivariate evaluation context. Leite et al. (2018b) and Silva et al. (2019) state that the breed is a model of adaptation to the semi-arid condition in Northeastern Brazil. The AI was adapted and calculated based on the interaction between variables studied (physiological parameters, haematology, electrolytes, acid–base status, mineral renal functions, metabolites, enzymes and proteins), and both phenotypes showed a high adaptation. However, a higher value was generated for the Red Morada Nova sheep (Fig. 3). The advantages of the red phenotype over the white animals range from the epidermal protection to efficient heat dissipation to the environment (Leite et al. 2020). Although the white phenotype was more distant from the reference values for sheep, the AI values were also high (close to 100), as expected, because studies with white Morada Nova sheep identified their high adaptive potential (Costa et al. 2018; Leite et al. 2018a). It is important to note that the animals had white fur but did

**Fig. 3** Adaptability Index of Morada Nova sheep with different coat colors



not have depigmented skin, which could lead to frequent health problems.

High differentiation between red and white coat of the Morada Nova sheep breed was studied by Ferreira et al. (2014), and this supports the other phenotypic differences found in our study. For the red variety, haematological traits were the most important, including electrolytes and acid–base status (Table 1). These were highlighted by Façanha et al. (2021) and Ferreira et al. (2021) evaluating dark coated sheep. Dark coat coloration increases the amount of heat absorbed at the animal's body surface and this causes an increase in body temperature (Maia et al. 2015), which increases energy expenditure for homeothermy balance. According to Silveira et al. (2019), blood is probably the most effective means the body has to contribute to the dissipation of sensible and latent heat during a heat stress condition through the skin and respiratory tract. In the white sheep, the adaptive profile did not seem as well defined. The main types of variables highlighted were one electrolyte ($K^+$), one serum protein (TP), one acid–base status variable ($PO_2$), one hematological parameter (HG), two serum metabolites (CHO and GLU), and one physiological parameter (RT). These phenotypic variations associated with high AI values for both populations of Morada Nova sheep reinforce the hypothesis that the breed is a well-adapted genetic resource and supports the use both varieties.

The development of evaluation indexes such as that of Vasconcelos et al. (2020) for dairy cows under tropical conditions and the adequacy for other species are helpful for this type of testing since it has a multivariate methodological format. In the future, this measurement could serve as a selection measure for efficient/adapted animals and could be used to direct crossbreeding.

## Conclusion

The AI was able to measure the adaptability level of Morada Nova sheep of different coat colors reared in a tropical region. Red Morada Nova sheep showed a better AI against environmental conditions with a high inference of the haematology, electrolytes and acid–base status on the adaptability. The White Morada Nova sheep had a more varied response, with the most critical variables being $K^+$, TP, $PO_2$, HG, CHO, RT and GLU. Therefore, this study concludes that both phenotypes of the Morada Nova sheep breed are well adapted to the climatic condition of the Brazilian tropical region using different adaptive mechanisms.

**Author contribution's** J. Ferreira and E.A. da Silva Methodological design and conceptualization of the idea, treatment and data analysis, writing and final revision.

J.E.R. de Sousa and D. Façanha: Supervision and administration of the experimental project, writing and final revision.

R.M.F. Silveira, R.L.D. da Costa and C.M. McManus: Final revising the manuscript critically for important intellectual content.

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**Data Availability** Database used for analysis: https://1drv.ms/x/c/651d44d610bd1ce1/EVNzXV8DJ5FDjmWiCTxTQpoB5EWcAmAwqfgRp5DtZvflow.

## Declarations

**Ethics approval** This experiment was approved by the Ethics Committee of the UFERSA (process number: 23091003895/2014–71).

**Conflict of interest** The authors declare that they have no conflicts of interest.

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