Effect of pulmonary arterial pressure and annual precipitation on reproductive performance of Angus heifers in south central Wyoming

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INTRODUCTION

In locations above 1,500 m of elevation, beef producers face the challenge of pulmonary hypertension, a condition that can result in high altitude disease. This hypoxic response can cause up to a twenty percent death loss in high altitude cattle herds (Williams et al., 2012). Reduced atmospheric oxygen at elevation, in combination with inefficient oxygen utilization by the bovine cardiopulmonary system, causes alveolar-hypoxia and pulmonary arterial vasoconstriction. With this vasoconstriction, significant development of pulmonary hypertension, right ventricular hypertrophy and progression into right ventricular dilation and failure occurs. Pulmonary arterial pressure (PAP) testing can indicate an animal’s disposition for pulmonary hypertension. According to the Beef Improvement Federation guidelines, low-risk PAP measures at 5,000 to 6,000 feet of elevation are between 34 to 39 mmHg, 40 to 45 mmHg are at moderate risk, 49 to 49 mmHg are high risk, and scores greater than 50 mmHg are at extreme risk of displaying signs of pulmonary hypertension. Management decisions can be made based on PAP phenotypes when managing individual animals for pulmonary hypertension.

Despite the economic importance of reproductive performance, little is known about how environmental factors such as precipitation influence reproduction of heifers at high altitude. Ambient temperature, humidity, radiation and wind have an influential effect on reproductive efficiency (Sánchez-Castro, 2021). Because of this, it is a concern that additional stress caused by differences in annual precipitation from year to year would compound physiological stress induced by high altitude; thus, causing decreased fertility during drought years. Therefore, the objective of this study investigated the effect of high altitude on reproductive performance in Angus heifers and how above and below annual precipitation interact with these effects. Subsequently, we hypothesized that PAP and environmental stress, such as annual precipitation, cumulatively and individually would have a negative effect on fertility.

MATERIALS AND METHODS

Data were collected using protocol (#KP 1526) approved by the instructional animal care and use committee at Colorado State University. The Colorado State University John E. Rouse Beef Improvement Center (CSU-BIC) located northeast of Encampment, WY, at an elevation of 2,150 to 2,411 m. The facility maintains 420 head of Angus mother cows in a commercial setting. Heifers were artificially inseminated during the third week of May at an average of 421.65 (± 20.95) days of age, following a CIDR-progesterone based estrus synchronization protocol. After AI
services were completed, females are exposed to natural service bulls for 60 d.

**Fertility and PAP**

Data were collected from historical records spanning the years 1993 to 2019. Data collected included 3,834 individual records consisting of identification, sire, dam, birth year, birth weight, weaning weight, yearling weight, mating year, artificial insemination technician (AI), AI sire, mating age, first service conception (FSC), age at first calving, PAP score, and PAP collection date. First service conception was determined through a pregnancy evaluation using ultrasonography via rectal palpation of females at 30- and 100-d post-AI. If a female was determined pregnant at the end of the breeding season through a pregnancy evaluation using ultrasonography via rectal palpation, overall heifer pregnancy (HPG) was assigned. If a female was found to be not pregnant, then she was culled. The PAP measures were collected when heifers were approximately 12 mo of age. The PAP collection was performed by the same Colorado/Wyoming licensed veterinarian every year using procedures described by Holt and Callan (2007). Briefly, a polyethylene catheter is inserted into the pulmonary artery. The mean logarithm of systolic and diastolic pulmonary artery pressure was collected via a pressure transducer connected to the catheter. Basing knowledge off risk factors associated with PAP, a PAP score of 41 and below was considered the cut off for females to a good candidate to be replacement females in the CSU-BIC herd.

**Annual Precipitation**

Precipitation data were collected from the National Oceanic and Atmospheric Administration (https://www.ncdc.noaa.gov/cag/). Data for Carbon County, Wyoming, were sourced for the years that fertility and PAP data were sourced (1993 to 2019), along with the historical average. Using this annual precipitation data, each calendar year was assigned a precipitation classification, “1” for above (A) average precipitation, or “0” for below (B) average precipitation. Using this knowledge, two response variables were created based on the precipitation classification (A/B variable). A birth year precipitation classification was created and a breeding year classification was created. This was done to assess the effect of precipitation on heifer fertility performance if above or below average precipitation was observed in the year of her birth and development or the year where conception and maintenance of pregnancy occurred.

**Data Analysis**

The relationships between PAP, fertility, and annual precipitation were assessed using four statistical models that were implemented for both birth year and breeding year in order to assess the effect of precipitation on each respective biological year of the females. Model 1 utilized linear regression to address PAP as a continuous variable. The remaining models, 2 to 4, executed a logistic regression due to fertility phenotypes being a binary outcome. The model equation is presented below:

\[ y_i = \mu + B_1x_1 + B_2x_2 + e_i \]

Where \( y_i \) was the vector of observed phenotypes for the trait of interest, which included PAP, FSC, and HPG, \( \mu \) was the overall mean of the observations, \( B_1 \) was the slope of the regression line of the continuous covariable, \( x_1 \) was the vector of predictor variables for the fixed effect of the continuous variable precipitation, \( B_2 \) was the parameter of the population regression line of the continuous fixed effect of age, \( x_2 \) was the vector of predictor variables for the continuous fixed effect of age, and \( e_i \) was the vector of random residuals. The phenotype and climate variables used in each model follows Table 1.

| Model | Trait | PAP A/B | AI Age | PAP*A/B | Yearling Year |
|-------|-------|---------|--------|---------|---------------|
| 1     | PAP   | x x     | X      |         |               |
| 2     | FSC/HPG | x x     | X      |         |               |
| 3     | FSC/HPG | x x     | X      |         |               |
| 4     | FSC/HPG | x x     | X      |         |               |

A/B, above or below precipitation; AI Age, age at artificial insemination; PAP*A/B, interaction between pulmonary arterial pressure (mmHg) and precipitation (above or below).
response. Biological year was not included; hence it did not need to be run for both breeding and birth year. All data were analyzed using the R statistical software package (R Core Team, 2020).

RESULTS

Results for annual precipitation and fertility are shown in Figure 1. Summary statistics for heifer fertility traits, age, and PAP are presented in Table 2. In regards to the breeding year models (Table 3), for model 1, age and precipitation were significant predictors of PAP ($P < 0.05$). In model 2, age accounted for variability in both HPG and FSC, while precipitation was only a significant predictor of HPG. Pulmonary arterial pressure was shown to be a significant predictor of HPG in model 3, while age again accounted for variation in both HPG and FSC. For model 4, age was a predictor of FSC. Age also predicted HPG; however, a tendency was observed for the interaction of age and rainfall as precipitation was an important source of variation in the analysis of HPG ($P = 0.09$).

As for birth year models (Table 4), precipitation and age were again significant predictors of PAP. However, in model 2, age was related to both FSC and HPG, while precipitation was an indicator for FSC. In the final model, age predicted both FSC and HPG, while PAP and its interaction with precipitation was an indicator for HPG. Overall, in both breeding and birth models, the amount of variation accounted by the models was limited ($R^2 < 0.014$). Finally, PAP and fertility traits were shown to have negative relationships according to their slope coefficients ($-0.0015$ to $-0.278$) while there were positive relationships between precipitation and the fertility traits (0.1376 to 0.5268) (Tables 3 and 4). Two exceptions were observed in these relationships, Model 2 for FSC and breeding year ($-0.0688$) and Model 4 HPG with birth year ($-0.7687$) had a negative relationship between precipitation and fertility traits.

DISCUSSION

In this study, using these data, we observed that PAP influenced HPG but not FSC. Ultimately, it is the hypoxic environment that leads to right side heart failure due to pulmonary hypertension. During a state of hypoxia, tissue becomes necrotic (Holt and Callan, 2007). This could be an issue if the uterine environment is negatively affected due to the lack of oxygen. The fetus is highly sensitive to changes in the uterine environment, which can lead to embryonic loss if a shift in oxygen supply

Table 2. Summary statistics for phenotypic observations of yearling Angus heifers ($n = 3,834$) raised at altitude (2,150–2,411 m)

| Phenotype  | Mean  | SD   | Minimum | Maximum |
|------------|-------|------|---------|---------|
| AI Age, days | 421.65 | 20.95 | 347     | 476     |
| PAP, mmHg   | 41.09  | 7.52 | 21      | 129     |
| FSC, %      | 47%    | 10%  | 27%     | 68%     |
| HPG, %      | 85%    | 8%   | 64%     | 96%     |

AI Age, age at artificial insemination.
The placenta facilitates the exchange of gases and liquids from dam to fetus. If the dam is hypoxic, it is plausible that the fetus is not receiving enough oxygen, even in the low oxygen environment of the uterus (Jauniaux et al., 2005). A dam that has a high PAP score may have reduced oxygen levels in comparison to low PAP individuals; therefore, these types of physiological phenomena may explain pregnancy rate differences between high and low PAP females.

Precipitation influenced both PAP and fertility rates in this study. Specifically, results were that precipitation in the breeding year affected HPG and precipitation and birth years influenced FSC. These results could be attributed to how forage nutrition is influenced by precipitation. It is known that drought and low precipitation will negatively affect the nutrient levels of forage (Scasta et al., 2015). If the forage is negatively affected during a breeding year, overall maintenance of pregnancy could be affected, explaining the relationship between precipitation and HPG in breeding years. However, it has been shown that heifers must reach 66% of their mature body weight to reach sexual maturity. If drought occurred during an animal's birth year and subsequent growth through about 9 mo of age, nutrients would be reduced, negatively affecting the growth and sexual development of the heifer. This could potentially affect her ability to be developed and sexually mature to conceive at first service by 421 d of age.

The relationship between PAP and fertility traits appears to be negative, which is expected. As PAP increases, fertility decreases. As for the relationship between precipitation and fertility, for the majority of the models, the relationship was positive. This is as one would expect, with more precipitation, fertility increases. However, for FSC, precipitation in the breeding year indicated a negative relationship. This could be explained from the aspect that precipitation received in Encampment, Wyoming in high precipitation years occurs as snow. This would mean that females would

Table 3. Results of models with explanatory variables and coefficient of determination values for breeding year models assessing relationship of PAP, precipitation (A/B), and age (AI Age) for data from yearling Angus heifers (n = 3,834) raised at altitude (2,150–2,411 m)

| Model  | Response | Effect (P-value) | Slope coefficients |
|--------|----------|----------------|--------------------|
|        |          | PAP  | A/B | AI Age | PAP*A/B | PAP  | A/B | R² |
| Model 1 | PAP      | <0.0001a | <0.0001a | 1.2020 | 0.0111 |
| Model 2 | FSC      | 0.2945 | 0.0060a | -0.0688 | 0.0028 |
|        | HPG      | 0.0237a | <0.0001a | 0.2114 | 0.0087 |
| Model 3 | FSC      | 0.0778 | <0.0001a | -0.0777 | 0.0033 |
|        | HPG      | 0.0015a | 0.0001a | -0.0177 | 0.0099 |
| Model 4 | FSC      | 0.7970 | 0.2220 | 0.1597 | -0.0015 | 0.4527 | 0.0040 |
|        | HPG      | 0.2002 | 0.0311a | <0.0001a | -0.0101 | 0.9924 | 0.0131 |

A/B, above or below precipitation; AI Age, age at artificial insemination; R², coefficient of determination; PAP*A/B, interaction between pulmonary arterial pressure (mmHg) and precipitation (above or below).

Within each column, superscripts indicate significance (P < 0.05).

Table 4. Results of models with explanatory variables and coefficient of determination value for birth year models assessing relationship of PAP, precipitation (A/B), and age (AI Age) for data from yearling Angus heifers (n = 3,834) raised at altitude (2,150–2,411 m)

| Model  | Response | Effect (P-value) | Slope coefficients |
|--------|----------|----------------|--------------------|
|        |          | PAP  | A/B | AI Age | PAP*A/B | PAP  | A/B | R² |
| Model 1 | PAP      | <0.0001a | <0.0001a | 1.2020 | 0.0111 |
| Model 2 | FSC      | 0.2945 | 0.0060a | -0.0688 | 0.0028 |
|        | HPG      | 0.0237a | <0.0001a | 0.2114 | 0.0087 |
| Model 3 | FSC      | 0.0778 | <0.0001a | -0.0777 | 0.0033 |
|        | HPG      | 0.0015a | 0.0001a | -0.0177 | 0.0099 |
| Model 4 | FSC      | 0.7970 | 0.2220 | 0.1597 | -0.0015 | 0.4527 | 0.0040 |
|        | HPG      | 0.2002 | 0.0311a | <0.0001a | -0.0101 | 0.9924 | 0.0131 |

A/B, above or below precipitation; AI Age, age at artificial insemination; R², coefficient of determination; PAP*A/B, interaction between pulmonary arterial pressure (mmHg) and precipitation (above or below).

Within each column, superscripts indicate significance (P < 0.05).
experience a harsh winter and cold stress immediately prior to breeding, potentially affecting their ability to conceive at first service (Sánchez-Castro, 2021). Investigating how defining precipitation ranking based on a biological year versus a calendar year could provide further insight into the relationship. Further research could also explore how multiple above or below average precipitation years in a row affect fertility and PAP. In conclusion, with low coefficients of determination, it was found that environmental factors such as altitude and precipitation were associated with fertility traits in yearling Angus heifers.

ACKNOWLEDGMENTS

The authors would like to acknowledge the University of Wyoming Extension Service, specifically Regional Extension Program Coordinator, USDA NPCH, Windy Kelley and Carbon County Rangeland Extension Educator, Abby Perry for their assistance locating precipitation data. This work is supported by USDA National Institute of Food and Agriculture Hatch project COLO0607A, accession number 1006304 and COLO0681A, accession number 1010007.

Conflict of interest statement. The authors declare that they have no conflict of interest.

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