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Abstract

Climate change is expected to not only increase the frequency of extreme weather events, but to also increase the variability of climate conditions within geographical locations. Within the context of climate, livestock genetics research has mostly focused on GxE interactions and on selection for specific environments. This approach, however, does not address the sensitivity of animals to unstable environmental conditions, a likely scenario due to climate change. In this study, we explored the association between the variation in climate variables and the historical trends of growth traits in American Angus beef cattle. Analyses were performed using historical climate data, and phenotypic records of birth, weaning and post-weaning weights from American Angus beef cattle over the last three decades, from herds covering a wide area of the United States of America (USA). Results suggest a greater variation of both phenotypic and genetic trends in regions with high climate variability.

Introduction

One of the most pressing issues that humanity faces is the challenge of feeding a continuously growing population in an environment that is being disrupted by climate change. Due to the current concerns related to climate change there is an immediate need for breeding programs to reduce the environmental footprint of animal production (*e.g.* methane emission) and at the same time increase the resilience of animals to environmental changes. This is particularly relevant for beef cattle production systems which are largely extensive, and animals are constantly exposed to a broad range of environments (*e.g.* heat stress, which has a negative effect on commercial traits in beef cattle (Bradford et al., 2016)). In terms of climate, livestock genetic research has mostly focused on estimation of GxE interactions (Fennewald et al., 2018) and on selection for specific environments, viz recent studies that evidenced within-breed genetic diversity associated with different ecoregions in the USA that were defined based on the historical means of several climate variables and topography (Blackburn et al., 2017; Braz et al., 2021; Rowan et al., 2021). However, one of the frequently noted outcomes of climate change is the increasing climate variability and frequency of extreme events (Trenberth et al., 2015; Stott, 2016). It may be the case that subregions within these ecoregions suffer differently the effect of climate variability over the years. The objective of this study was to explore the association between the variability of climate conditions and the historical growth traits trends in American Angus beef cattle.

Materials & Methods

Animal performance data. Phenotypic and pedigree information was provided by the American Angus Association. We performed the analysis on phenotypes recorded between 1990 and 2019 from 448 herds, all herds with at least 25 years of records and a minimum of 10 records per year-season (two seasons defined). Birth weight (BW), weaning weight (WW) and post-weaning weight (PWW) were recorded for a total of 1,754,310 Angus cattle.

Climate data. We used historical time-series climate data from 2,334 weather stations spread across the continental USA (Menne et al., 2012). Eight variables[1] based on temperature and precipitation were selected from weather stations with at least 25 years of records between 1990 and 2019. A Principal Component Analysis (PCA) was carried out using the standard deviation and skewedness of each of the eight variables for each station during the period of interest. From this PCA, we used the squared cosine (COS2) of the components to calculate the distance of a given observation (station) from the center of the system. COS2 was then used as a proxy for each station's climate variability (ClimVar). Finally, we classified the weather stations into five ClimVar groups using the values of COS2 as: low [0-0.2], medium-low (0.2-0.4], medium (0.4-0.6], medium-high (0.6-0.8] and high (0.8-1]. Using GPS coordinates, the herds used in this study were associated to each weather station and their corresponding ClimVar group.

Genetic evaluation model. Variance components and estimated breeding values (EBV) were obtained using a single trait model $\boldsymbol{y} = \boldsymbol{Xb} + \boldsymbol{Za} + \boldsymbol{e}$, where **y** are the phenotype records (of BW, WW or PWW); $\boldsymbol{b}$ are the coefficients of the fixed effects (herd-year-season – 16,047 levels; sex – two levels, male or female; age of the dam at calving – four levels, 2yo, 3-5yo, 6yo, or 7-12yo; for WW and PWW the linear and quadratic effects of the age of the animal was included as well) and $\boldsymbol{X}$ is their design matrix; $\boldsymbol{a} \sim N(\boldsymbol{0}, \boldsymbol{A}\sigma_a^2)$ are the breeding values and **Z** is their design matrix, with $\boldsymbol{A}$ as the numerator relationship matrix based on the pedigree; $\boldsymbol{e} \sim N(\boldsymbol{0}, \boldsymbol{I}_n\sigma_e^2)$ are n random residuals. $\boldsymbol{A}$ was built tracing three generations back from the animal with records and comprised 2,208,105 animals. The analyses were implemented using airemlf90 which is part of the BLUPF90 family of programs (Misztal et al., 2014).

Results

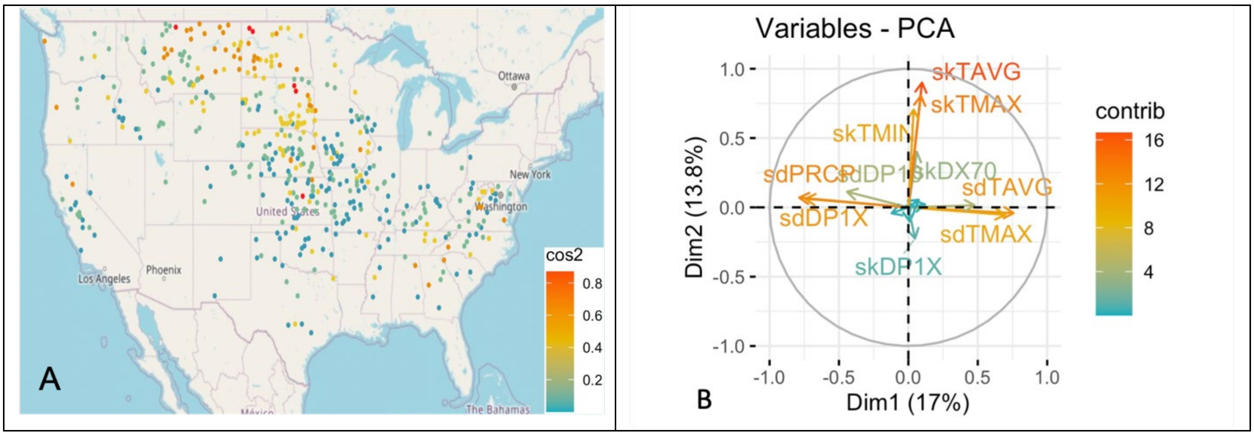

Figure 1. (A) Location of Angus herds classified by cosine square (COS2) distances; (B) Contribution of the skewness and standard deviation of each climate variable used to build COS2.

Figure 1 shows (A) the geographical location of the herds used in the analysis and their ClimVar grouping; and (B) the contribution of the skewness and standard deviation of each of the eight climate variables used to classify the herds into a ClimVar group. We noticed that herds located in the central-north region of the country were closer to locations with higher ClimVar during the analyzed period. These locations mostly correspond to the ecoregion denominated 'high

[1] Average mean, maximum and minimum temperature in the year, total precipitation per year, number of days with maximum temperature >= 21.1 ˚C in the year, number of days with maximum temperature >=32.2 ˚C in the year, number of days with >= 2.54 millimeters precipitation in the year, number of days with >= 25.4 millimeters precipitation in the year.

plains' by Braz et al. (2021). Approximately 40% of the phenotypic records were from herds classified as medium to high ClimVar. The variables with a higher contribution in the PCA analysis were the standard deviations of the average and maximum temperature (sdTAVG and sdTMAX), and the variables related to precipitation, *i.e.* the variability of the total amount of precipitation per year (sdPRCP) and the number of days with >=25.4 mm of rain in the year (sdDP1X). We also observed that the skewness of the average, maximum and minimum temperatures (skTAVG, skTMAX, skTMIN) were relevant, although mostly associated with the second component of the PCA analysis. Figure 2 shows the average phenotypic, genetic, and residual trends by year of birth, for herds located in the five ClimVar groups. We observed a decreasing trend for BW, while WW and PWW showed an increasing trend along the years. These trends are in line with the general emphasis given to selection traits in beef cattle breeding programs. Herds associated with high ClimVar showed a more irregular trend, especially for phenotypes.

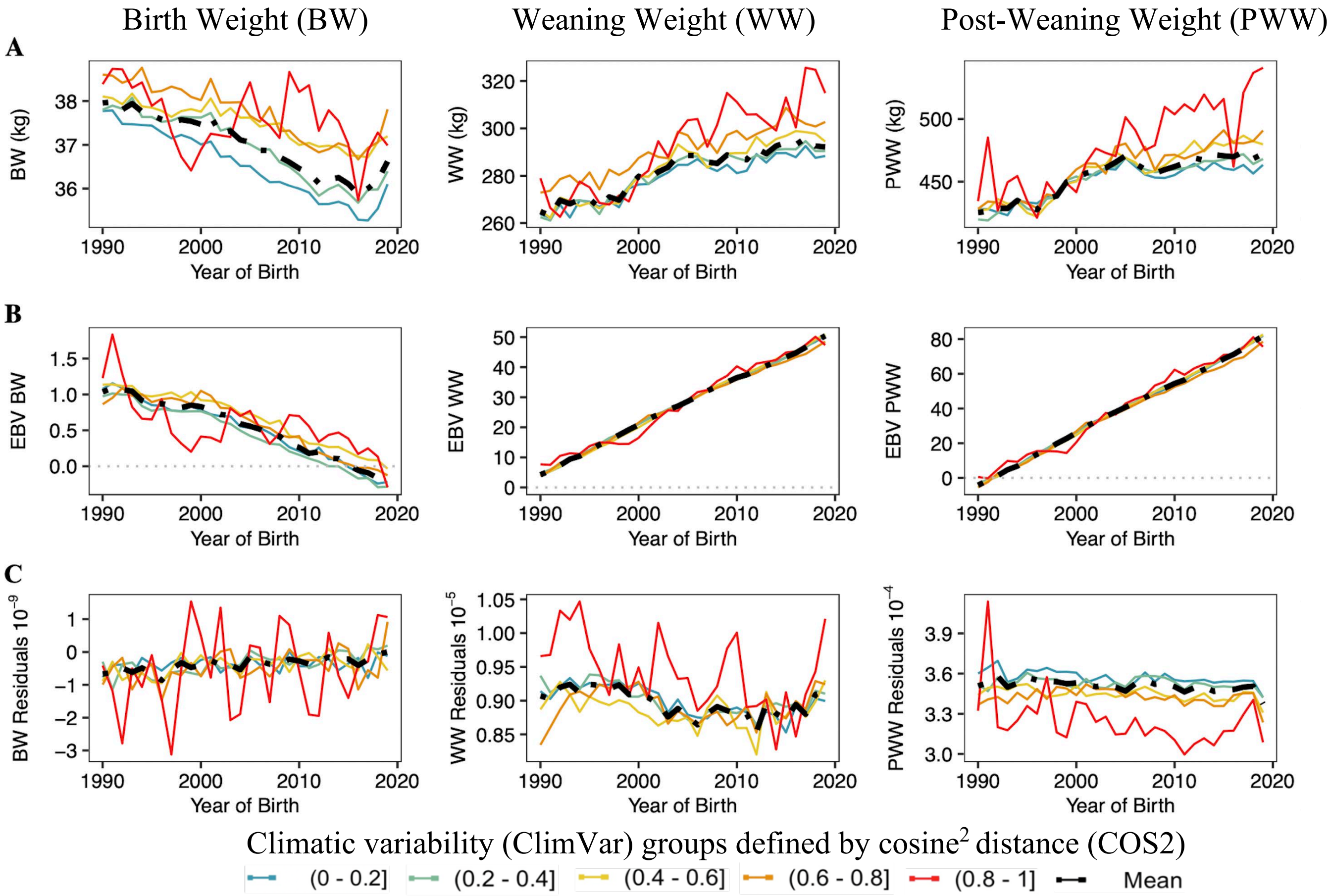

Figure 2. Average (A) phenotypic, (B) genetic, and (C) residual trends by birth year for herds located in the five ClimVar groups, for birth weight (BW), weaning weight (WW) and post-weaning weight (PWW).

A greater difference between the extreme ClimVar groups (low and high) was observed for phenotypic and genetic trends of BW, a rather unexpected result since BW is a phenotype modulated by the maternal environment and should be less directly influenced by changing weather conditions. The residual trends of the herds classified as high ClimVar were distinct for all three traits, however in the three traits residuals were more unstable for herds in the highest ClimVar locations.

Discussion

The USA uses ~45% of its area for agriculture and livestock production (The World Bank, 2021), which spans a large area with very different climate conditions. Previous studies suggested that the information from different ecoregions based on historical climate data averages can be useful for beef cattle production (e.g. Blackburn et al., 2017; Braz et al., 2021). Here, instead of considering these different ecoregions, we considered the climate variability over the last 30 years to geographically distinguish herds by classifying them in five climate variability (ClimVar) groups. High ClimVar was detected in several regions of the USA. Our objective was to examine the trends of Angus beef cattle growth traits in herds with 25 to 30 years of records when the environmental conditions are unstable (*i.e.* high ClimVar). These trends showed higher variability across the years when compared to herds in more stable weather conditions, although it should be noted that a smaller number of herds were in these high ClimVar locations. The phenotypic trajectory of the higher ClimVar groups were above the mean trajectory, but it was less obvious for the genetic trends. Then, it is possible that the unstable climate condition biased mostly to beneficial conditions or that the management system adopted effectively neutralized the climate variability. The model used to obtain EBVs included the environmental effect of the contemporary group, however ClimVar groups showed different patterns indicating that more environmental effects could be accounted for in the model. These results reinforce the idea that the inclusion of climate variables and the development of novel methodologies can be of value for traditional genetic and phenotypic prediction models. Additionally, analyses that account for climate variability may be an alternative method to evaluate resilience to environmental changes instead of the use of specific environmental stressors.

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