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The impact of shelter housing on the live weight gain of male calves in Yocará (Juliaca, Peru)

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Abstract

In the southern highlands of Peru, shelters for male calves are enclosed structures designed to protect them from extreme cold and solar radiation. Therefore, maintaining adequate climatic conditions in these shelters is key to optimizing live weight gain. The objective of the study was to estimate the impact of the shelter's climatic conditions on the live weight gain of male calves in the community of Yocará (Juliaca, Peru). A quasi-experimental research design was used, based on primary data and an eight-month follow-up. The results show that calves housed in shelters with better climatic conditions, as measured by the Temperature-Humidity Index (THI), achieved an average positive and statistically significant daily live weight gain of 0.106 kg ($p < 0.05$), compared to the scenario without such infrastructure. These findings highlight the importance of adequate livestock infrastructure in increasing live weight gain. It is recommended to strengthen public policies aimed at improving and expanding the construction of livestock shelters with enhanced designs that promote animal welfare and live weight gain.

Keywords: Counterfactual, Infrastructure, Male calves, Synthetic control, Weight gain.

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1. Introduction

The use of housing shelters for male calves has proven to be an effective practice for improving live weight gain, both under controlled conditions and in rural settings. Thus, the combination of proper housing and adequate nutrition is key to optimizing calf performance. These practices not only enhance productivity but also contribute to animal welfare and the sustainability of livestock farming [1-4].

Globally, the use of calf housing shelters has shown a significant positive impact on live weight gain, especially in contexts with adverse climatic conditions. Productive indicators such as daily weight gain have improved by 20% to 40%, while the feed conversion ratio has become more efficient (from 6:1 to 4.5:1). This is due to the reduction of thermal stress and the improvement of animal comfort. Additionally, evidence from North America and Europe has shown that these systems significantly reduce the incidence of respiratory diseases and neonatal mortality, reinforcing their effectiveness as a comprehensive management tool in livestock production. As such, this practice aligns with international animal welfare and sustainability standards, such as those promoted by GlobalG.A.P., by providing better housing conditions and promoting the healthy growth of livestock [5-8].

In developing countries, including those in Latin America, livestock farming represents one of the main alternatives for improving the living conditions of the population [9]. Small-scale cattle farming units in rural households play a fundamental role in generating economic income [10]. Given that livestock farming significantly contributes to the economy and social well-being of rural communities, it is important to consider the impact of environmental factors on livestock production, as is the case worldwide [11]. In this context, climatic conditions and infrastructure design directly influence the development and weight of male calves, affecting the profitability of livestock operations. Proper management under favorable conditions can generate additional income [12], and one key strategy to improve this income is increasing the weight of male calves through improved rearing conditions.

Peru is no exception to the influence of environmental conditions on improving livestock productivity. The use of housing shelters has also had a significant impact on livestock production, particularly in high Andean areas that are especially affected by frost and cold spells during the dry season. For example, through the Agro Rural program, 3,260 shelters were implemented in 15 regions in 2024, benefiting more than 390,000 head of livestock. These infrastructures have helped reduce mortality among calves and mothers by up to 35%, as evidenced in regions such as Junín, Moquegua, and Tacna. Although there are no specific figures on live weight gain in male calves, the improved shelter, health, and nutrition conditions provided by the shelters create a favorable environment for their development, potentially increasing daily weight gain and the overall productivity of the livestock system [13-16].

Furthermore, in southern Peru one of the areas most affected by climatic conditions, ambient temperatures during the months of June through August range from -25°C to 10°C. These extreme fluctuations cause climatic anomalies [17] and often lead to daily temperature variations greater than 25 °C, with frost occurring at night. This severely affects young animals [18]. making calf care a challenge for many dairy farms and significantly impacting weight productivity [19].

The department of Puno, known for its cattle-rearing activity, plays a key role in the survival strategies of the rural population [20]. However, this activity has been hampered by low animal weight productivity due to thermal fluctuations, which directly affect livestock performance. This highlights the need to promote the construction of shelters as resting and protection areas for cattle against extreme weather conditions, such as low temperatures, heavy rains, strong winds, and direct sun exposure [9].

In this context, the care of male calves is essential to ensure their growth and development, especially considering that weight gain up to eight months of age is crucial for their health in youth and adulthood [21]. Therefore, it is necessary to provide appropriate housing shelters for calves, with clean, dry, and well-ventilated environments [22]. Additionally, housing technologies must be adapted to local climatic conditions to prevent calves from being exposed to daytime heat and nighttime cold [23].

It must be clearly understood that in livestock activities, young calves are particularly sensitive to adverse environmental conditions [24]. Exposure to excessive heat or extreme cold significantly affects the live weight of male calves [2, 25, 26]. Extremely cold and humid weather has a negative impact on male calves born in winter and early spring, especially when combined with rainfall, increasing the risk of live weight loss [27]. low temperatures in shelters for newborn calves directly affect their health and survival [28].

For this reason, the study area part of the high Andean plateau region experiences sub-zero temperatures during the dry season (June to August), particularly at night, which negatively affects livestock productivity [29] this situation is caused by a combination of extreme environmental conditions such as air temperature, relative humidity, wind speed, solar radiation, and precipitation. These conditions often create unsuitable environments for the normal development of livestock, hindering the thermal comfort needed for animal welfare [30-33].

In this regard, livestock shelters increase the Temperature-Humidity Index (THI) inside, generating a more favorable microclimate that reduces the energy expenditure required for thermoregulation, thereby improving live weight gain. By generating internal temperatures 3 to 6 °C higher than outside and reducing relative humidity, shelters help animals stay within a more tolerable thermal range, which decreases morbidity and mortality and supports more efficient and sustained growth. This improvement in thermal conditions is especially relevant in the high Andean regions of Puno, where the THI can reach critical levels for livestock health and development [31]. This contrasts with the current condition of shelters, which are often precarious or poorly designed, negatively affecting the live weight gain of male calves. Therefore, the design of new shelters for small-scale intensive livestock systems is justified, with the goal of mitigating extreme air temperature fluctuations [34-36]. Consequently, the objective of the study was to estimate the impact of climatic conditions in livestock shelters on the live weight gain of male calves in the community of Yocará (Juliaca, Peru).

2. Materials and Methods

2.1. Research Approach, Type, and Design

The study adopts a quantitative approach aimed at measuring the impact of livestock infrastructure on the productive performance of male calves in high Andean conditions, using objective indicators such as the Temperature-Humidity Index

(THI) and Daily Live Weight Gain (DLWG). A quasi-experimental research design was employed to evaluate the effect of a non-random intervention (improved shelter) under real livestock management conditions. A single-case design with synthetic control was used, in which one treated calf was compared to a synthetic counterfactual composed of four calves from the control group, selected through purposive sampling.

2.2. Analysis and Characteristics of the Variables

At the beginning of 2023, in the Yocará sector, all small-scale livestock units had precarious shelters basic, low-quality shelters for cattle, which prompted the intervention of the Agroideas and Agro Rural programs of the Ministry of Agrarian Development and Irrigation of the Peruvian government. These programs co-financed the construction of new shelters to improve livestock protection against extreme cold. Participation by small-scale farmers in the program was voluntary, resulting in two groups: one with intervention (new shelters) and one without.

To ensure comparability, one livestock unit with a new shelter and another without intervention were selected. Initially, from four male calves in the treatment shelter, one was selected using purposive sampling based on similarity to the control group calves, while the remaining three were excluded from the analysis. Thus, the final sample comprised one treated calf and four control calves. The study was structured around a pre-treatment period (January–February 2023), ensuring similar baseline conditions. In March 2023, the treatment period began with the use of the new shelters, allowing for the evaluation of their impact on live weight gain. This methodological design ensured that observed differences could be attributed exclusively to the treatment, reinforcing the validity and rigor of the results obtained.

Furthermore, both treatment and control shelters are located in the same community, geographically close to one another (an average linear distance of 500 meters), and at similar altitudes; the treatment shelter is at 3,830 meters above sea level, while the control shelter is at 3,832 meters. The annual average temperature ranges between 4°C and 10°C. The area features predominantly flat terrain with slight undulations, characteristic of the high Andean plains. This minimal altitude difference ensures that environmental conditions such as temperature, humidity, and atmospheric pressure are virtually identical for both groups.

While climate is a relevant factor in the weight gain of male calves, it is not the only one. Other factors, such as a balanced and development-stage-appropriate diet, access to veterinary care (including vaccination, deworming, and disease control), overall management, animal welfare, weaning age, and supplementation, also play key roles. A healthy environment and proper management reduce stress and support more efficient growth. However, in this study, these factors were kept consistent across both groups, ensuring that observed differences in outcomes can be primarily attributed to the effect of the treatment i.e., the shelter implemented through the program and built with a new design is considered the treatment shelter (T=1), while the older, physically precarious shelter is considered the control shelter (T=0). Notably, both shelters have different physical characteristics and climatic conditions (Table 1).

Table 1.
Physical characteristics of the treatment and control shelter environments.

Shelter Characteristics	**Treatment (T=1)**	**Control (T=0)**
Built area (m2)	80.12	75.5
Wall Material	Concrete Block	Adobe
Roof Material	Galvanized Sheet Metal	Galvanized Sheet Metal
Floor Material	Concrete	Earth
Age of the shelter (in years)	0.5	12.5
Presence of Drainage	Yes	Not

The comparison between shelters indicates that the treatment shelter (T=1) has a larger area, concrete block walls, a concrete floor, and drainage; whereas the control shelter (T=0) is built with adobe, has an earthen floor, is older, more difficult to clean, and lacks drainage, making it precarious and inadequate. These conditions promote moisture accumulation, which does not provide optimal thermal comfort. Initially, wind speed was considered a factor that could intensify the impact of low temperatures on the calves. However, in this study, the animals were housed in shelters, which reduced direct exposure to wind.

Additionally, data on indoor air temperature (Ta) and relative humidity (Hr) in the shelters were collected from January 3, 2023, to August 30, 2023, continuously over 24 hours with a recording interval of 30 minutes, using the MX1101 HOBO Data Logger thermo hygrometer. Subsequently, the Temperature-Humidity Index (THI) was calculated as an indicator of thermal comfort for both treatment and control shelters, using the equation applied by Valtorta and Gallardo [37], NOAA [38], Jo, et al. [39] and Ravagnolo, et al. [40]:

$$\mathrm{THI} = (1{,}8 * \mathrm{Ta} + 32) - \left[\left(0{,}55 - 0{,}55 * \frac{\mathrm{Hr}}{100}\right) * (1{,}8 * \mathrm{Ta} - 26.8)\right]$$

The THI thresholds defined by Sumi and Tsuchiya [41] are oriented toward extreme heat situations and tropical climates, where a THI above 84 represents an emergency, values between 78 and 84 indicate danger, and values between 72 and 79 signal a thermal stress alert. A THI below 72 is considered normal, with no adverse effects on livestock productivity. Therefore, as part of the applied methodology, these criteria were considered. However, in high Andean regions such as the Altiplano of Puno (above 3,800 meters above sea level), which face adverse environmental conditions and temperatures that can drop below 0°C, there are no specific studies establishing THI thresholds adapted to these extreme cold conditions.

2.3. Research Method

The Synthetic Control Method (SCM) was used, which is suitable for studies with a single intervention and small sample sizes, as it allows for the construction of a weighted counterfactual from observationally similar control units [42]. This method is applied due to the impossibility of randomly assigning male calves to the treatment and control shelters, enabling the isolation of the effect of the improved shelter on the weight gain of male calves [43, 44].

Moreover, it is well known that male calves, during their first months of life and under normal conditions, experience progressive increases in live weight and body development from birth through adulthood. There is a typical growth curve for calf weight with a positive slope [24, 45-47]. The weight of a calf at birth is P_0 at time t_0. Assuming that the period from t_0 to t_1 corresponds to the pre-treatment phase without intervention, the treatment period begins at t_1. From this point, the evolution of the calf's weight under treatment (T=1) is compared with a counterfactual scenario without the improved infrastructure (T=0*). At time t_2, the expected impact is measured as the difference between points B and C.

The key question is: How would the calf's weight have evolved if it had not received the treatment? Since it is not possible to observe both P_3 (point B) and P_2 (point C) simultaneously in the same calf, the challenge lies in estimating the value of P_2. This requires an appropriate methodology to construct the counterfactual (Figure 1).

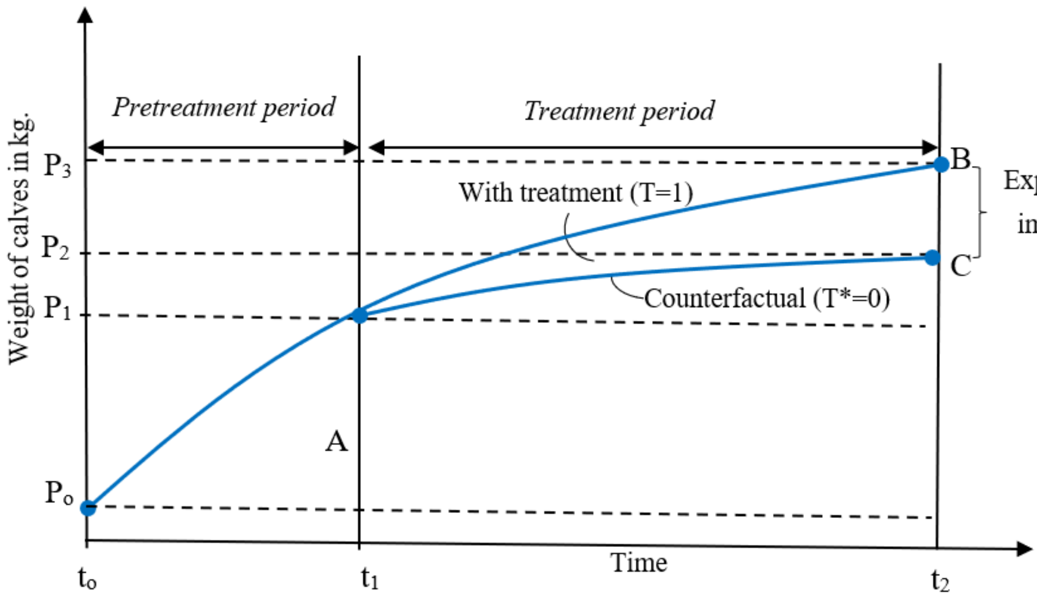

Figure 1.
Impact of the Shelter on the Weight of Male Calves.
Source: Own elaboration based on Abadie and Gardeazabal [48].

To answer the question, one of the strategies for estimating P_2 is precisely the application of the quasi-experimental Synthetic Control Method (SCM). This method involves constructing a comparison group from calves that did not receive the treatment, assigning greater statistical weight to those with characteristics most similar to the treated calf. A weighted average of the weights of these untreated calves is then calculated, providing a more accurate estimate of the weight the treated calf would have had in the absence of the treatment. This estimated value represents the counterfactual scenario, allowing the evaluation of the treatment's impact by comparing the observed live weight with the estimated live weight without intervention.

It is important to note that the study used purposive sampling within the Synthetic Control Method (SCM) framework to ensure comparability and minimize bias, selecting calves with observable characteristics similar to the treated calf. This approach enabled the construction of a precise synthetic control, avoiding the variability of random sampling and ensuring that post-treatment differences could be attributed to the intervention. Conventional random sampling methods were not applied, as they did not guarantee the selection of comparable units, which could have compromised the validity of the analysis. Although efforts were made to include other calves from the new shelter, differences in age, weight, or health status prevented their inclusion in the SCM.

Therefore, the choice of one treated calf and four male control calves is methodologically justified within the synthetic control framework, where the treated unit represents a specific case study, and the controls are combined to construct a valid counterfactual [43]. In experimental studies with small samples, selecting a single treated individual helps reduce heterogeneity within the treatment group and focuses on the effect of the intervention [49]. Other male calves housed in the treatment shelter were excluded due to possible differences in early development or individual conditions that could bias the estimation of the treatment's impact [50]. Moreover, the differential weighting of control calves ensures that the comparison is based on units more representative of the expected behavior in the absence of intervention, thereby strengthening the internal validity of the analysis [51].

Indeed, to ensure that the observed impact is exclusively attributable to the treatment shelter, one calf from the treatment group and four male calves from the control group were selected based on shared characteristics, denoted as (Z), following the approach proposed by Holgado, et al. [52] the characteristics considered included: birth weight, calf age, birth order, interval between births, feed intake, number of vaccinations, and age of the dam (Table 2). Data on these characteristics were obtained from the clinical records of each calf, and the evolution of live weight was monitored monthly at the end of each month over a period of eight consecutive months, from January to August 2023, using a SCALE COW 2T MITMAQ scale.

Table 2.
Observable characteristics of the calf and the dam.

Notation	Description	Quantification
Y	Weight gain of the calf	kg.
Z1	Birth weight of the calf	kg.
Z2	Age of the calf	Days
Z3	Age of the dam	Days
Z4	Birth order	1 = first, 2 = second, 3 = third
Z5	Birth interval	Days
Z6	Vaccine against foot-and-mouth disease	Yes = 1; No = 0
Z7	Vaccine against clostridiosis	Yes = 1; No = 0
Z8	Vaccine against pasteurellosis	Yes = 1; No = 0
Z9	Intake of balanced feed	Yes = 1; No = 0
Z10	Intake of nutritional supplements	Yes = 1; No = 0
Z11	Conserved and improved forage	Yes = 1; No = 0

Based on the observable characteristics (Z_j) of the untreated (control) male calves, what is known as the synthetic calf is constructed. The weight w_j^* is obtained through a minimization of squared error procedure, comparing the characteristics of the treated calf with a weighted combination of the untreated calves. Mathematically, w_j^* is calculated by finding the set of weights that minimize the sum of the squared differences between the observable characteristics of the treated male calf and those of the untreated calves. That is:

$$\mathrm{w}_j^* = \mathrm{argmin}\left[\left(\mathrm{Z}_{11t} - \sum_{i=2}^{J} \mathrm{w}_j \mathrm{Z}_{1jt}\right)^2 + \cdots + \left(\mathrm{Z}_{k1t} - \sum_{i=2}^{J} \mathrm{w}_j \mathrm{Z}_{kjt}\right)^2\right]$$

The optimal weighting w_j^* represents the weight assigned to each calf "j" from the control shelter in period t, while ZkjtZ_(kjt) Zkjt corresponds to the value of the k-th observable characteristic of those calves. It is important to note that Z represents the set of observable characteristics of the calves, with the treated calf defined as the first element (Z_1). Once the optimal weights are calculated, a balance of the observable variables is performed using the weighted average of each variable before and after the treatment. The impact of the treated shelter ($\widehat{\alpha}_{it}$) is then obtained as the difference between the observed weight of the treated calf and the weighted average of the male calves housed in the control shelter, also referred to as the synthetic control calf or counterfactual.

$$\widehat{\alpha}_{it} = \mathrm{Y}_{1t} - \sum_{j=2}^{J+1} \mathrm{w}_j^* \mathrm{Y}_{jt}$$

2.4. Model Proposed in the Study

As shown in Figure 1, Daily Live Weight Gain (DLWG) is a key indicator in livestock production, as it measures the growth and development of animals based on their diet, management, and environmental conditions [53]. This parameter allows for the evaluation of production system efficiency and the impact of various management strategies, such as nutritional supplementation and infrastructure improvements, on animal performance [54]. In impact studies that employ the synthetic control method, DLWG is used to estimate the difference in growth between animals subjected to a specific treatment and their counterfactual, thereby isolating the effect of the intervention.

$$DLWG = \frac{\left(Peso_{T,f} - Peso_{S,f}\right) - \left(Peso_{T,i} - Peso_{S,i}\right)}{D}$$

Where:
$Weight_{T,f}$ is the weight of the treated calf at the final month of the post-treatment period (t_2).
$Weight_{S,f}$ is the weight of the synthetic calf at the final month of the post-treatment period.
$Weight_{T,i}$ is the weight of the treated calf at the last month of the pre-treatment period (t_1).
$PWeight_{S,i}$ is the weight of the synthetic calf at the last month of the pre-treatment period.
D is the number of days elapsed during the post-treatment period.

2.5. Population and Sample

The population consists of male calves under one year of age in family livestock units in the high Andean community of Puno. The sample includes one treated male calf (new shelter) and four control male calves (precarious shelter), selected through purposive sampling based on observable homogeneity criteria (weight, age, diet, vaccination, etc.).

2.6. Source of Information

The primary source includes monthly weight records of the calves and climatic data collected using HOBO MX1101 data loggers (frequency: every 30 minutes). Secondary sources include technical standards, scientific literature, and local livestock records.

2.7. Research Ethics

The study complies with Law No. 30407, the Animal Protection and Welfare Law of Peru. No invasive treatments were applied during this research. All procedures adhered to ethical principles for animal research, and monitoring was conducted under normal management conditions.

3. Results

According to the results obtained, in terms of temperature and thermal comfort, the treatment shelter exhibited higher and more stable values, with an average interior temperature of 15.02 °C, compared to 8.03 °C in the control group, which was notably lower. The Temperature-Humidity Index (THI) reflected a more favorable environment in the treatment shelter (63.12 ± 1.74), while the control shelter showed a lower index (55.38 ± 2.49), confirming improved housing conditions in the treatment scenario (Table 3).

After monitoring climatic variables over an eight-month period in 2023, it was observed that the small livestock unit with treatment (T=1) maintained a more comfortable interior temperature, ranging around 15.02 ± 2.09 °C. In contrast, the livestock unit in the control group (T=0) recorded a less comfortable interior temperature, varying around 8.03 ± 2.39 °C. The Temperature-Humidity Index (THI) indicated that the treatment shelter provided better climatic conditions, with values around 63.12 ± 1.74, compared to the control shelters, which showed an average index of 55.38 ± 2.49. This demonstrates that there are statistically significant differences ($p < 0.05$) between the treatment and control shelters (Table 3).

Table 3.
Characteristics of housing sheds in treatment and control groups.

Characteristics	Treatment (T=1)	Control (T=0)
Average indoor temperature (°C)	15.02	8.03
Minimum and maximum indoor temperature (°C)	[8.07 – 22.79]	[-0.55 – 17.63]
Relative humidity (%)	35.43	40.88
Minimum and maximum relative humidity (%)	[3.95 – 65.37]	[4.41 – 72.12]
Temperature and Humidity Index (THI)	63.12 ± 1.74	55.38 ± 2.49
Sample size (n)	11,520	11,220

From a statistical standpoint, the results of the student's t-test for mean comparison confirm the existence of significant differences in the Temperature-Humidity Index (THI) between the treatment shelter and the control shelter, with a 1% significance level (Table 3), indicating notable variations in environmental conditions between both groups. Therefore, the treatment shelter offers better environmental conditions than the control shelter, based on the THI (Table 3).

According to Table 4, which presents the evolution of weight (in kg) of one treated calf and a control group (n=4) over eight months, a progressive weight increase is observed in both groups, although variability is present in both the treated calf and the control calves. Furthermore, from the perspective of the synthetic control method, this variability is a key aspect in evaluating the treatment's effectiveness. Within this framework, the weight of the treated calf is compared to a counterfactual constructed from a weighted combination of the control group calves, allowing the isolation of the treatment's impact and ensuring that the observed post-intervention differences in weight are attributable exclusively to the treatment and not to other external factors (Table 4).

Table 4.
Weight progression (kg) of male calves in the treatment and control groups.

	Treated Male Calf (n=1)	Control Male Calves (n=4)			
Year 2023	**i=1**	**j=1**	**j=2**	**j=3**	**j=4**
January	32.15	34.56	30.12	32.86	32.45
February	74.33	72.33	75.27	77.21	78.22
March	100.34	110.00	98.99	108.95	112.34
April	131.44	130.33	118.95	125.67	125.33
May	153.67	142.44	132.44	140.31	142.44
June	168.98	155.34	145.60	158.90	157.89
July	179.00	165.56	155.00	165.56	167.90
August	189.25	178.55	172.25	175.60	177.80

In this regard, the treated calf initially started with a lower weight (32.15 kg in January) compared to the average of the control group (approximately 32.50 kg), but from March onwards, it began to surpass the control average in weight gain. By August, the treated calf reached 189.25 kg, while the average for the control group was approximately 176.55 kg; this represents a weight gain of 157.10 kg for the treated animal versus an average of 144.05 kg for the controls, suggesting a possible positive effect of the treatment on the animal's development. Furthermore, the treated calf exhibited more accelerated growth from March, which could be associated with the implementation of the treatment. In contrast, some variability was observed within the control group: for example, j=1 showed slower growth, while j=4 performed better and more consistently. This pattern highlights the influence of individual factors (such as genetics or environmental responsiveness) in addition to the treatment. Although the results are encouraging, the fact that there was only one animal in the treatment group limits the ability to generalize the findings, making it advisable to expand the sample size to validate these results with greater statistical robustness (Table 4).

Regarding feeding, both groups of calves (treatment and control) received the same diet, commonly used by local farmers, which ensured the comparability of results. The nutritional plan included controlled milk feeding and a gradual transition to solid feed. During the first three months, the animals received decreasing amounts of milk: 6 liters daily in the first month, 4 liters in the second, and 2 liters in the third, with milk being completely phased out by the fourth month. Simultaneously, from the first month, a balanced starter supplement was offered, consisting of grains, plant-based proteins, digestible fiber, vitamins, and minerals, designed to support male calf development. From the second month onward, forage (such as alfalfa or oat hay) was introduced in increasing amounts, reaching 6 kg daily by the eighth month. Additionally, the calves had continuous access to fresh water throughout the entire period, ensuring proper hydration and facilitating adaptation to solid feed (Table 5).

This standardized nutritional management not only allowed the effects of the treatment to be compared under uniform conditions but also ensured proper physiological development in both groups. The early introduction of starter feed and forage enabled a smooth and efficient transition of the digestive system, reducing weaning stress and promoting better feed conversion. This nutritional strategy was designed in accordance with livestock practices adapted to the region, and its uniform application across all calves minimized the diet's influence as a variable in the growth outcomes. On the other hand, it is worth noting that none of the calves were castrated, as this is not a common practice in the local production context, where males are primarily destined for sale or reproduction. This decision strengthens the external validity of the study by maintaining conditions representative of the regional production system (Table 5).

Table 5.
Feeding plan for male calves according to age and experimental group.

Age (months)	**Treatment**			**Control**		
	Milk (L/day)	**Supplement (kg/day)**	**Forage (kg/day)**	**Milk (L/day)**	**Supplement (kg/day)**	**Forage (kg/day)**
0	6	6	0	6	6	0
1	6	6	0.5±0.01	6	6	0.5±0.01
2	4	4	1.5±0.01	4	4	1.5±0.01
3	2	2	2.5±0.02	2	2	2.5±0.02
4	0	0	3.5±0.05	0	0	3.5±0.05
5	0	0	4.5±0.05	0	0	4.5±0.05
6	0	0	5.0±0.10	0	0	5.0±0.10
7	0	0	5.5±0.10	0	0	5.5±0.10
8	0	0	6.0±0.10	0	0	6.0±0.10

In this regard, although detailed clinical records were not maintained, daily observations were conducted to monitor the condition of the calves. Health monitoring allowed for the identification of mild neonatal diarrhea cases in both the treated and control groups. These episodes were effectively managed through rehydration and veterinary treatment, without complications. No respiratory diseases or severe pathologies were recorded, and the incidence of diarrhea was low and similar across both groups. This health follow-up helped minimize the impact of external factors on calf performance, ensuring that the observed differences were primarily associated with the conditions of the shelter.

Before estimating the treatment effect, the synthetic control method was applied to construct a comparable counterpart to the treated calf, enabling isolation of the shelter's impact as the only relevant difference. Table 6 presents the results of the balancing of observable variables, in which optimal weights (w*) were applied to ensure that the distributions of the treated calf and its synthetic counterpart were equivalent in terms of mean and variance. This methodological procedure is crucial for reducing bias in the comparison, as it controls for variables that could affect animal growth, such as birth weight, dam's age, or birth order. The variables "feed intake" and "types of vaccines" were not significant in the balancing model, suggesting that they did not contribute to explaining differences between the observed units, possibly because they were homogeneous between groups or did not differentially influence the outcomes.

The analysis indicates a high degree of similarity between the treated and synthetic calves in the most relevant variables. For instance, birth weight was nearly identical (30.35 kg vs. 30.04 kg), as was the age of the mother (1230 vs. 1230.89 days) and the birth order (second parity in both cases). These similarities strengthen the validity of the counterfactual, as the animals' initial biological and reproductive characteristics were appropriately controlled. Although minor differences were recorded in the calf's age (4 days vs. 7.29 days) and birth interval (795 days vs. 691.47 days), these were not significant enough to compromise the comparison, remaining within acceptable margins of biological variability. Overall, these results validate the use of the synthetic control as a robust tool to evaluate the treatment's impact, as they allow weight gain differences to be more confidently attributed to the shelter effect rather than to imbalanced initial conditions between the units of analysis (Table 6).

Table 6.
Balancing of key observable characteristics of the calf.

Variables	Treated Calf	Synthetic Calf
Calf birth weight (kg)	30.35	30.04
Calf age (days)	4	7.29
Mother's age (days)	1230.0	1230.89
Birth order	2	2
Birth interval (days)	795.00	691.47

In this regard, Table 7 presents the monthly evolution of the live weight of the treated calf compared to its synthetic counterpart, which was generated using the synthetic control method to estimate the impact of the shelter as a structural intervention. The post-treatment period begins at the end of March, from which point significant differences between the two weights start to appear. In the first three months (January–March), the differences are minimal, confirming a good pre-treatment model fit, supported by an RMSPE of 1.386; this indicates that the synthetic calf's weight closely replicates the actual calf's weight trajectory before receiving the treatment. Moreover, the construction of the synthetic calf was based almost entirely on the weights of two animals from the control group, with a weighting of 95.1% from calf i=3 and 4.9% from calf j=2, further reinforcing the validity of the counterfactual by focusing on the most comparable control units.

Table 7.
Impact of the treated shelter on live weight gain.

Year 2023	Treated Calf Weight (kg)	Synthetic Calf Weight (kg)	Impact in kg $\hat{\alpha}_{1t}$
January	32.15	30.34	--
February	74.33	75.08	--
March	100.34	99.53	0.81
April	131.44	119.51	11.93**
May	153.67	132.93	20.74**
June	168.98	146.08	22.90**
July	179.00	155.52	23.48**
August	189.25	172.56	16.69**
Weight gain/animal/day		(16.69-0.81)/150=0.106 kg	

Furthermore, during the post-treatment period (April–August), the impact of the improved shelter is reflected in a sustained and significant increase in live weight. Starting from an initial difference of 0.81 kg in March, a peak of 23.48 kg is reached in July, with a cumulative impact of 16.69 kg by the end of August compared to the synthetic calf. This result translates into an average additional daily weight gain of 0.106 kg per animal over 150 days. The improvement in the performance of the treated calf can be attributed to more favorable environmental conditions within the shelter, which reduce thermal stress and promote a more stable growth environment, especially within the challenging climatic conditions of the high Andes. These results show that housing infrastructure not only has a significant effect on animal welfare but also on key productive indicators such as weight gain, with direct implications for livestock system efficiency and producer profitability (Table 7).

Therefore, considering the synthetic control model, which allows for the construction of a reliable counterfactual by weighting only the most similar control units to the treated calf thereby minimizing bias from unobserved variables the low Root Mean Square Prediction Error (RMSPE = 1.386) during the pre-treatment period indicates that differences in weight after March are not attributable to model mismatch, but to the causal effect of the treatment. Furthermore, with diet, health management, and other production conditions kept constant between the groups, the likelihood that external factors explain the weight differential is significantly reduced. In this regard, the average increase of 0.106 kg/day in the treated calf's weight gain can be confidently attributed to the microenvironmental improvements provided by the shelter, including better thermal protection, reduced exposure to environmental stress, and enhanced comfort factors that directly influence metabolic efficiency and feed conversion.

This is confirmed by the results shown in Figure 2, where the weight of the synthetic control calf matches closely with that of the treated calf during the pre-treatment period (months 1 to 3), validating the initial balance and ensuring that any subsequent differences are solely due to the treatment. However, following the implementation of the shelter (from month 3 onward), the treated calves show a higher weight gain compared to the synthetic group, indicating a positive impact of the infrastructure on livestock productivity. Thus, the observed difference between the treated unit and its synthetic control represents the estimated impact of the treatment.

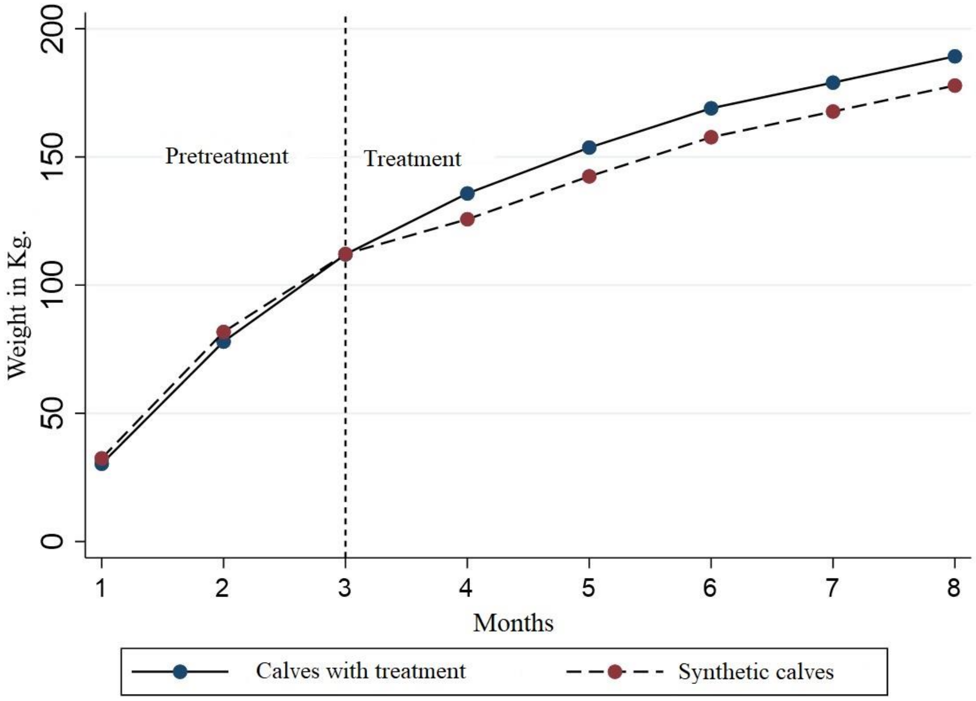

Figure 2.
Impact of the shelter on the weight gain of male calves.

4. Discussion

According to the findings, air temperature and relative humidity have a direct impact on the survival of cattle, particularly male calves. This aligns with the observations of Wohlfahrt et al. [55]. As these additional factors, such as indoor temperature, relative humidity, and solar radiation, significantly influence the weight gain of these animals, especially when air temperature falls outside the thermoneutral zone. That is, when it is above or below the optimal thermal comfort ranges for male calves [23]. In this context, studies like that of Peña, et al. [22] demonstrated that weight gain in male calves is considerably higher in housing environments with favorable conditions. This evidence underscores the importance of designing and maintaining infrastructures that help mitigate the negative effects of climate fluctuations, thereby maximizing animal welfare and performance. Optimizing environmental conditions in shelters is, therefore, essential to ensure proper development and sustained weight gain in male calves throughout their growth phases.

Regarding the Temperature-Humidity Index (THI), used as an indicator of the thermal environment, which allows us to evaluate the relationship between temperature and humidity, critical values for minimum, average, and maximum THI have been established at 64, 72, and 76, respectively, consistent with the results of Igono, et al. [55]. These findings coincide with those of Manriquez et al. [57], who demonstrated that male calves exposed to environments with temperatures ranging from -1.3 to 38.4°C and relative humidity varying between 9.8% and 99.7% showed an average weight gain of 1.30 kg/day. These results highlight the importance of adequate infrastructure, which can have significant positive effects on both the health and productive performance of male calves, as noted by Borderas, et al. [56].

In the case of extreme cold and humid climates, especially when combined with precipitation, it negatively affects calves born in winter and early spring, increasing the risk of lower weight gain and reducing animal survival [57]. Animals face physiological limits against extreme temperatures, a phenomenon widely studied in animal bioclimatology since the 1950s [6]. Therefore, although environmental changes can somewhat mitigate thermal stress caused by extreme cold and heat [58] thermal comfort varies with the age of the calves; newborns require temperatures between 15 and 26°C, while one-month-old calves can tolerate temperatures between 10 and 24°C [23].

Cold-induced thermal stress affects the metabolism, feed efficiency, and immune function of calves, resulting in reduced weight gain due to the increased energy expenditure required for thermoregulation [59, 60]. In the high plateau of Puno, at over 3,800 meters above sea level, these effects can intensify due to low temperatures and hypoxia, compromising nutrient absorption and weakening the immune response, increasing susceptibility to diseases, and affecting the productive performance of calves. This aligns with the findings of Demateis-Llera et al. [63], adaptive strategies, such as dietary adjustments and the use of shelters, can mitigate these effects, optimizing weight gain and improving animal welfare. It is important to note that, while numerous studies have addressed the thresholds of the Temperature-Humidity Index (THI) in warm climates, research in cold regions remains limited. In the study area, specific THI thresholds have not been determined, making it difficult to accurately assess thermal stress and implement appropriate strategies. Therefore, conducting more detailed studies to establish clear references is crucial for optimizing livestock management and welfare under low-temperature conditions.

In terms of methodological validity, a placebo test was implemented, referencing previous studies by Galiani and Quistorff [61] and Ferman and Pinto [62] to confirm that the observed effect was exclusively due to the shelter treatment, the results demonstrated that the impacts on treated units were significantly greater, confirming the validity of the estimated effect of shelters in this study. The placebo test reinforces the idea that the observed effects are not due to chance but are a direct consequence of the intervention, validating the impact of shelters on calf productivity. This methodological strategy, which allows for the dismissal of spurious impacts and validation of causal effects, is essential to ensure the robustness of the results [63].

In this regard, constructing synthetic controls allowed for comparing the gaps between treated and untreated groups and verifying that the impacts on treated units were statistically significant ($p<0.05$), reinforcing the reliability and validity of the results obtained by Bertrand, et al. [63]. Additionally, the results align with previous research emphasizing the importance of placebo tests in validating the causal effects of interventions in production systems [61]. Thus, it is confirmed that shelters significantly improve environmental conditions and livestock productivity in the Peruvian highlands, contributing to a more favorable environment for calf growth and development [64].

In this context, various previous studies have reported variations in the daily weight gain of male calves, ranging from an average of 0.20 kg/day [65] with ranges between 0.24±0.17 and 0.29±0.22 kg/day in small farms [66]. Moreover, in more favorable environments, gain can reach up to 1.15 kg/day in beef cattle in tropical climates [67] while an increase in ambient temperature during the first month of life has been associated with a 0.012 kg/day increase [68]. However, under traditional feeding conditions, productivity decreases significantly during the dry season [69].

Regarding the evaluation of the impact of shelter infrastructure on the daily weight gain of Brown Swiss calves, an increase of 0.106 kg/day was observed in those calves housed in shelters in the highlands of Puno, at over 3,800 meters above sea level. This highlights the importance of protection from extreme weather conditions. However, when compared to previous studies, such as Quispe Coaquira, et al. [19] in Puno (3,825 meters above sea level), which reported a daily gain of 0.57 kg/day in a semi-intensive system with pastures and supplementation, and Rojas [70] In Amazonas (2,400 meters above sea level), where daily gains ranged from 0.54 kg/day without shelter to 0.70 kg/day with portable shelters and supplementation, it is observed that these studies do not specifically evaluate the impact of infrastructure on weight gain but rather describe differences in weight gain under various management conditions. These differences suggest that factors such as altitude, climate, and production system play a crucial role in the growth of calves, emphasizing the need to design strategies adapted to each environment to optimize livestock productivity.

Moreover, shelters, as structures that improve environmental conditions, can significantly contribute to the live weight gain of calves in the Peruvian highlands. Similar studies have shown that dietary supplementation can considerably improve performance, with weight gains ranging between 0.20 kg/day and 0.29 kg/day in small-scale farms [65]. These results, combined with the observation that shelters provide a more controlled environment, emphasize the importance of improving environmental conditions to enhance calf development, particularly in areas such as the highlands, where extreme weather conditions pose a challenge to livestock productivity. According to the obtained results, with an average daily gain of 0.20 kg/day with supplementation, ranging from 0.24±0.17 to 0.29±0.22 kg/day, the findings align with those of Gitau, et al. [66] who reported a gain of 0.45 kg/day in other small-scale farms. Additionally, Hyde, et al. [68] found that an increase in the average ambient temperature during the first month of male calves' lives can increase weight gain by 0.012 kg/day, highlighting the importance of shelters, especially in environments with adverse weather conditions. These results recommend that improving environmental conditions for male calves can have a significant impact on their productive development in areas like the highlands of Puno.

Furthermore, different types of shelter accommodation, such as barns, provide essential protection for the growth and development of male calves [34]. These structures help mitigate the effects of adverse weather conditions, providing a more controlled environment that favors animal welfare. Additionally, there are various ways to help the young calf better adapt to an appropriate ambient temperature after birth, which is crucial for its early development [71]. However, the impact of thermal stress on male calves still requires further investigation. Studies on this topic could constitute a relevant new research line, as understanding how different degrees of thermal stress affect the health and performance of male calves would allow for improvements in management practices and housing design [72]. This field of study could have important implications for the development of strategies to mitigate the negative effects of climate change on livestock.

This reinforces the conclusion that adequate infrastructure will not only contribute to the live weight gain of male calves but also significantly reduce morbidity and mortality, as it facilitates the physiological adaptation of animals to cope with stress from both cold and heat [28]. Shelters, designed technically in the correct way, are a priority need in the Peruvian highlands, as they help mitigate exposure to heat during the day and cold at night, which is especially crucial for young male calves [22]. Furthermore, research such as that by Hill, et al. [73] has demonstrated that male calves raised in shelters have a live weight gain of up to 6% higher compared to those raised in simple enclosures, reinforcing the importance of having proper infrastructure to ensure optimal animal development.

It is crucial to promote training on the design of shelters for the protection of male calves and the proper management of young animals [34]. It is also essential to provide access to information that improves farmers' knowledge and capabilities, contributing to the implementation of good livestock management practices; this enables the optimization of production systems in challenging conditions, such as those in the highlands, and enhances the overall welfare of the animals.

Therefore, shelters create microclimates that provide a more controlled environment for male calves, favoring their growth. However, when weather conditions worsen, live weight gains are significantly reduced. This same response is observed in heifers, who also experience a decrease in weight gain under adverse weather conditions [74]. In previous studies, daily weight gains for male calves fed balanced diets ranged between 0.40 kg/day and 0.47 kg/day [75]. extreme changes in weather conditions, such as intense cold and heat, cause stress in lactating male calves, negatively influencing their live weight gain [76], highlighting the importance of proper management of climatic conditions within shelters to minimize the impact of thermal stress and improve the productivity of male calves.

Finally, studies such as those by Dalla Vía and Gallego [77] demonstrated that the live weight gain of male calves averaged 0.60 kg/day up to 10 days of age, and thereafter, weight gain may vary over time. In the case of 4-month-old heifers, it was observed that they reached a weight of 70 kg or more [78]. However, in this study, the weight gain was significantly lower compared to other cases, with a recorded gain of 0.106 kg/day for male calves. Adverse weather is a key factor that negatively affects productive efficiency and livestock development, limiting the animals' ability to reach their optimal growth potential [79]. Therefore, there is a need to continue researching and optimizing calf management and housing conditions to mitigate the effects of extreme weather in the Peruvian highlands. In this context, it is crucial to expand studies on thermal stress in high-altitude livestock farming, with special emphasis on cold stress, as low temperatures in Puno affect the health and productivity of calves. Strategies for mitigation, such as improving shelters, nutritional supplementation, and environmental monitoring, are recommended to strengthen the resilience of livestock in the face of adverse weather conditions.

5. Conclusions

It was determined that the livestock unit with the treatment (improved shelter) maintained significantly more favorable thermal conditions, with an average internal temperature of 15.02 ± 2.09 °C, compared to 8.03 ± 2.39 °C recorded in the control unit. Similarly, the Temperature-Humidity Index (THI) was considerably more comfortable in the treated shelter (63.12 ± 1.74), compared to the values recorded in the control (55.38 ± 2.49), demonstrating a significant difference between the two infrastructures.

The new shelter design, aimed at improving internal microclimatic conditions, had a positive and statistically significant effect on the daily weight gain of male calves. On average, the animals housed in the treated shelter achieved an additional gain of 0.106 kg/animal/day, compared to the counterfactual scenario without treatment. The application of synthetic control methods and placebo tests confirmed the robustness of these results, demonstrating that the observed impact is solely attributable to the intervention and not to random or external factors. This validates the effectiveness of shelters as a tool for improving body development and animal welfare, even in climatically adverse environments such as the highlands of Puno.

In this context, it is recommended to promote the implementation of public policies aimed at strengthening livestock infrastructure in high Andean areas. It is a priority to support the design and construction of thermally efficient shelters that ensure suitable conditions for calf growth, thereby reducing the effects of thermal stress. Although the Ministry of Agrarian Development and Irrigation (MIDAGRI), through the Agro Rural program, has made significant progress through the subsidy and co-financing of shelters, it is necessary to expand the coverage of these programs to benefit a greater number of small-scale producers in vulnerable areas.

Likewise, it is suggested to optimize the current shelter design by incorporating insulating materials, controlled ventilation systems, and efficient drainage, in order to improve internal thermal comfort and the durability of the structures. Finally, it is recommended to create economic incentives and technical training programs that encourage the adoption of management practices adapted to extreme climatic conditions, thereby promoting more resilient, efficient, and sustainable livestock production in the high Andean regions of the country.

References

[1] S. Van Ausdal, "Pasture, profit, and power: An environmental history of cattle ranching in Colombia, 1850–1950," Geoforum, vol. 40, no. 5, pp. 707-719, 2009. http://dx.doi.org/10.1016/j.geoforum.2008.09.012
[2] L. Roland, M. Drillich, D. Klein-Jöbstl, and M. Iwersen, "Invited review: Influence of climatic conditions on the development, performance, and health of calves," Journal of Dairy Science, vol. 99, no. 4, pp. 2438-2452, 2016. https://doi.org/10.3168/jds.2015-9901
[3] I. Lorenz, B. Earley, J. Gilmore, I. Hogan, E. Kennedy, and S. J. More, "Calf health from birth to weaning. III. Housing and management of calf pneumonia," Irish Veterinary Journal, vol. 64, pp. 1-9, 2011.
[4] L. Fiems, S. De Campeneere, B. Cottyn, and C. Boucque, "Effect of housing on the performance of double-muscled rearing calves," in *Annales de Zootechnie*, 1998, vol. 47, no. 3, pp. 207-214.
[5] J. Becker *et al.*, "Effects of the novel concept 'outdoor veal calf'on antimicrobial use, mortality and weight gain in Switzerland," Preventive Veterinary Medicine, vol. 176, p. 104907, 2020.
[6] R. Black, B. Whitlock, and P. Krawczel, "Effect of maternal exercise on calf dry matter intake, weight gain, behavior, and cortisol concentrations at disbudding and weaning," Journal of Dairy Science, vol. 100, no. 9, pp. 7390-7400, 2017.
[7] E. Miller-Cushon and T. DeVries, "Effect of social housing on the development of feeding behavior and social feeding preferences of dairy calves," Journal of Dairy Science, vol. 99, no. 2, pp. 1406-1417, 2016.
[8] M. B. Jensen, L. R. Duve, and D. Weary, "Pair housing and enhanced milk allowance increase play behavior and improve performance in dairy calves," Journal of Dairy Science, vol. 98, no. 4, pp. 2568-2575, 2015.
[9] M. Mutenje *et al.*, "Understanding breeding preferences among small-scale cattle producers: Implications for livestock improvement programmes," Animal, vol. 14, no. 8, pp. 1757-1767, 2020.
[10] M. Faisal *et al.*, "Assessing small livestock herders' adaptation to climate variability and its impact on livestock losses and poverty," Climate Risk Management, vol. 34, p. 100358, 2021.
[11] R. R. P. Domínguez *et al.*, "Análisis de costos y estrategias productivas en la lechería de pequeña escala en el periodo 2000–2012," Contaduría y administración, vol. 59, no. 2, pp. 253-275, 2014.

[12] F. F. Chaiña-Chura, D. Salas-Avila, M. Hermoza-Gutierrez, D. Salas-Mercado, and W. Quispe-Borda, "horizontal communication: Identification of the social demand for agricultural technology in the Peruvian Altiplano, Puno," Comuni@cción, vol. 12, no. 4, pp. 282-295, 2021.

[13] D. J. Wilson *et al.*, "A focus group study of Ontario dairy producer perspectives on neonatal care of male and female calves," Journal of Dairy Science, vol. 104, no. 5, pp. 6080-6095, 2021.

[14] G. A. Abanto, M. Karkri, G. Lefebvre, M. Horn, J. L. Solis, and M. M. Gómez, "Thermal properties of adobe employed in Peruvian rural areas: Experimental results and numerical simulation of a traditional bio-composite material," Case Studies in Construction Materials, vol. 6, pp. 177-191, 2017.

[15] A. O. Obafemi and S. Kurt, "Environmental impacts of adobe as a building material: The north cyprus traditional building case," Case Studies in Construction Materials, vol. 4, pp. 32-41, 2016.

[16] M. R. Rodríguez, "How to build a prototype adobe dome using a popular technique," Revista Legado de Arquitectura y Diseño, vol. 19, pp. 1-18, 2016.

[17] SENAMHI, *Climate monitoring and forecasting (National Climate Bulletin, Vol. July, Report No. 1)*. Lima, Peru: SENAMHI, 2018.

[18] R. Andressen, M. Monasterio, and L. F. Terceros, "Climate regimes of the southern Bolivian plateau: A region affected by desertification," Revista Geográfica Venezolana, vol. 48, no. 1, pp. 11-32, 2007.

[19] J. Quispe Coaquira, C. Belizario Quispe, E. Apaza Zúñiga, Z. Maquera Marón, and V. Quisocala Carita, "Productive performance of Brown Swiss cattle in peruvian high plains," Journal of High Andean Research, vol. 18, no. 4, pp. 411–421, 2016.

[20] R. P. Paredes Mamani and F. Escobar-Mamani, "The role of livestock and poverty in rural Puno," Revista de Investigaciones Altoandinas, vol. 20, no. 1, pp. 39-60, 2018.

[21] W. Villasmil, Y. Ontiveros, D. Durán, and B. Guzmán, "Maternal grand sire and birth season on senepol calves grown in Yaracuy Syaye, Venezuela," Technical Note. Revista Cientifica FCV-LUZ, vol. 11, no. 6, pp. 510–516, 2001.

[22] G. Peña, C. Risco, E. Kunihiro, M. Thatcher, and P. Pinedo, "Effect of housing type on health and performance of preweaned dairy calves during summer in Florida," Journal of Dairy Science, vol. 99, no. 2, pp. 1655-1662, 2016.

[23] C. Saravia and G. Cruz, *Influence of the atmospheric environment on animal adaptation and production*. Montevideo: University of the Republic, 2003.

[24] G. M. Martinez, F. Demateis Llera, A. Otero, and E. Lopez Seco, "Impact of heat stress on dairy calves on physiological and behavioral parameters," Revista FAVE. Sección Ciencias veterinarias, vol. 19, no. 2, pp. 65-68, 2020. https://doi.org/10.14409/favecv.v19i2.9058

[25] D. J. Bell, J. Robertson, A. I. Macrae, A. Jennings, C. S. Mason, and M. J. Haskell, "The effect of the climatic housing environment on the growth of dairy-bred calves in the first month of life on a Scottish farm," Animals, vol. 11, no. 9, p. 2516, 2021. https://doi.org/10.3390/ani11092516

[26] F. López-González, M. G. Cantú-Patiño, Ó. Gama-Garduño, F. Prospero-Bernal, V. Colín-Navarro, and C. M. Arriaga-Jordan, "Tall fescue and ryegrass pastures for grazing dairy cows in small-scale dairy systems in the highlands of Central Mexico," Tropical and Subtropical Agroecosystems, vol. 23, no. 2, pp. 1-10, 2020. https://doi.org/10.56369/tsaes.3126

[27] D. V. Armstrong, "Heat stress interaction with shade and cooling," Journal of dairy science, vol. 77, no. 7, pp. 2044-2050, 1994.

[28] F. L. M. Silva and C. M. M. Bittar, "Thermogenesis and some rearing strategies of dairy calves at low temperature–a review," Journal of Applied Animal Research, vol. 47, no. 1, pp. 115-122, 2019.

[29] B. Dado-Senn *et al.*, "Pre-and postnatal heat stress abatement affects dairy calf thermoregulation and performance," Journal of dairy science, vol. 103, no. 5, pp. 4822-4837, 2020.

[30] S. Azzam *et al.*, "Environmental effects on neonatal mortality of beef calves," Journal of Animal Science, vol. 71, no. 2, pp. 282-290, 1993.

[31] E. López-Quiñonez, F. I. Albarrán-Tamayo, J. Ramírez-Emiliano, B. Bañuelos-Hernández, and A. Cruz-Hernández, "Temperature and humidity index (THI) supported by Hair Cortisol in dairy cows for chronic caloric stress measurement," Nova Scientia, vol. 13, no. 27, 2021.

[32] K. V. Nordlund and C. E. Halbach, "Calf barn design to optimize health and ease of management," Veterinary Clinics: Food Animal Practice, vol. 35, no. 1, pp. 29-45, 2019.

[33] M. Molina Huelva and P. Fernández Ans, "Evolution of thermal behavior in traditional stone and thatched houses: Enhancement of a sustainable model in northwest Spain," Revista de la Construcción, vol. 12, no. 2, pp. 102-115, 2013.

[34] S. A. Mahendran, N. Blackie, D. C. Wathes, and R. E. Booth, "Comparison of environment quality measurements between 3 types of calf housing in the United Kingdom," Journal of Dairy Science, vol. 106, no. 4, pp. 2461-2474, 2023.

[35] J. Valdivia-Cruz, J. Reyes-González, and G. Valdés-Paneque, "Effect of temperature and humidity index (THI) on the physiological responses of grazing dairy cows," Cuban Journal of Agricultural Science, vol. 55, no. 1, pp. 21-29, 2021.

[36] L. Kovács, F. Kézér, P. Póti, N. Boros, and K. Nagy, "Upper critical temperature-humidity index for dairy calves based on physiological stress variables," Journal of Dairy Science, vol. 103, no. 3, pp. 2707-2710, 2020.

[37] S. Valtorta and M. Gallardo, "Heat stress in dairy production," Instituto Nacional de Tecnología Agropecuaria, Estación Experimenta Rafaela, Argentina. Miscelánea, vol. 81, pp. 173–85, 1996.

[38] NOAA, "Livestock hot weather stress. Kansas: US department of commerce, national oceanic and atmospheric administration (NOAA), National weather service central region," Regional Operations Manual Letter pp. C-31–76, 1976.

[39] Y.-H. Jo, W.-S. Kim, D.-Q. Peng, J. G. Nejad, and H.-G. Lee, "Effects of different energy levels and two levels of temperature–humidity indices on growth, blood metabolites, and stress biomarkers in Korean native calves," Journal of Thermal Biology, vol. 117, p. 103703, 2023.

[40] O. Ravagnolo, I. Misztal, and G. Hoogenboom, "Genetic component of heat stress in dairy cattle, development of heat index function," Journal of Dairy Science, vol. 83, no. 9, pp. 2120-2125, 2000.

[41] K. Sumi and Y. Tsuchiya, "Evaluating the toxic hazard of fires," Retrieved: https://web.mit.edu/parmstr/Public/NRCan/CanBldgDigests/cbd197_e.html. [Accessed 1987. [Online]. Available: https://web.mit.edu/parmstr/Public/NRCan/CanBldgDigests/cbd197_e.html

[42] W. Shadish and T. Cook, *Campbel DT. Experimental and quasi-experimental designs for generalized causal inference Houghton*. Boston New York: Mifflin and Compañy, 2002.
[43] A. Abadie, A. Diamond, and J. Hainmueller, "Synthetic control methods for comparative case studies: Estimating the effect of California's tobacco control program," Journal of the American statistical Association, vol. 105, no. 490, pp. 493-505, 2010.
[44] G. W. Imbens and J. M. Wooldridge, "Recent developments in the econometrics of program evaluation," Journal of economic literature, vol. 47, no. 1, pp. 5-86, 2009.
[45] M. Van Eetvelde, M. M. Kamal, L. Vandaele, and G. Opsomer, "Season of birth is associated with first-lactation milk yield in Holstein Friesian cattle," Animal, vol. 11, no. 12, pp. 2252-2259, 2017.
[46] D. Agudelo, "Growth curves of cattle grown at corporación universitaria Lasallista," Revista Lasallista de Investigación, vol. 1, no. 2, pp. 42–45, 2004.
[47] J. Domínguez-Viveros *et al.*, "Characterization of growth of Cebu cattle in testing performance on grazing," Ecosistemas y recursos agropecuarios, vol. 4, no. 11, pp. 341-348, 2017.
[48] A. Abadie and J. Gardeazabal, "The economic costs of conflict: A case study of the Basque Country," American Economic Review, vol. 93, no. 1, pp. 113-132, 2003. https://doi.org/10.1257/000282803321455188
[49] A. Abadie, "Using synthetic controls: Feasibility, data requirements, and methodological aspects," Journal of economic literature, vol. 59, no. 2, pp. 391-425, 2021.
[50] E. Cavallo, S. Galiani, I. Noy, and J. Pantano, "Catastrophic natural disasters and economic growth," Review of Economics and Statistics, vol. 95, no. 5, pp. 1549-1561, 2013.
[51] L. Gobillon and T. Magnac, "Regional policy evaluation: Interactive fixed effects and synthetic controls," Review of Economics and Statistics, vol. 98, no. 3, pp. 535-551, 2016.
[52] F. Holgado, M. Ortega, J. Fernández, and M. Hernández, "Ganancia diaria de peso predestete en terneros de vacas criollas y F1 Criollo-Jersey," Actas Iberoamericanas en Conservación Animal AICA, vol. 8, pp. 5-8, 2016.
[53] L. O. Tedeschi, D. P. Bureau, P. R. Ferket, and N. L. Trottier, "ASAS-NANP SYMPOSIUM: Mathematical modeling in animal nutrition: training the future generation in data and predictive analytics for sustainable development. A Summary," Journal of Animal Science, vol. 99, no. 2, p. skab023, 2021.
[54] L. Moraes, J. Fadel, A. Castillo, D. Casper, J. Tricarico, and E. Kebreab, "Modeling the trade-off between diet costs and methane emissions: A goal programming approach," Journal of dairy science, vol. 98, no. 8, pp. 5557-5571, 2015.
[55] M. Igono, G. Bjotvedt, and H. Sanford-Crane, "Environmental profile and critical temperature effects on milk production of Holstein cows in desert climate," International journal of biometeorology, vol. 36, pp. 77-87, 1992.
[56] F. T. Borderas, A. M. B. de Passillé, and J. Rushen, "Temperature preferences and feed level of the newborn dairy calf," Applied Animal Behaviour Science, vol. 120, no. 1-2, pp. 56-61, 2009.
[57] R. E. Rawson *et al.*, "Health and metabolic responses of young calves housed at-30 degrees C to-8 degrees C," Canadian Journal of Veterinary Research, vol. 53, no. 3, p. 268, 1989.
[58] F. Gwazdauskas, "Effects of climate on reproduction in cattle," Journal of Dairy Science, vol. 68, no. 6, pp. 1568-1578, 1985.
[59] S. H. Esmail, "Digestive, metabolic and production responses to cold stress," Retrieved: https://es.allaboutfeed.net/respuestas-digestivas-metabolicas-y-de-produccion-al-estres-por-frio/. [Accessed 2019. [Online]. Available: https://es.allaboutfeed.net/respuestas-digestivas-metabolicas-y-de-produccion-al-estres-por-frio/
[60] M. Odeón and S. Romera, "Estrés en ganado: Causas y consecuencias," Revista Veterinaria, vol. 28, no. 1, pp. 69-77, 2017.
[61] S. Galiani and B. Quistorff, "The synth_runner package: Utilities to automate synthetic control estimation using synth," The Stata Journal, vol. 17, no. 4, pp. 834-849, 2017. https://doi.org/10.1177/1536867X1801700404
[62] B. Ferman and C. Pinto, " Placebo tests for synthetic controls," Munich Personal RePEc Archive, vol. 2017, no. 78079, pp. 1–24, 2017.
[63] M. Bertrand, E. Duflo, and S. Mullainathan, "How much should we trust differences-in-differences estimates?," The Quarterly journal of economics, vol. 119, no. 1, pp. 249-275, 2004.
[64] K. H. Brodersen, F. Gallusser, J. Koehler, N. Remy, and S. L. Scott, "Inferring causal impact using Bayesian structural time-series models," Annals of Applied Statistics, vol. 9, no. 1, pp. 247–274, 2015.
[65] D. Makau *et al.*, "Effects of Calliandra and Sesbania supplementation on weight gain in dairy calves on smallholder farms in Kenya," Preventive Veterinary Medicine, vol. 172, p. 104787, 2019.
[66] G. Gitau, J. J. McDermott, B. McDermott, and B. D. Perry, "The impact of Theileria parva infections and other factors on calf mean daily weight gains in smallholder dairy farms in Murang'a District, Kenya," Preventive Veterinary Medicine, vol. 51, no. 3-4, pp. 149-160, 2001.
[67] I. Berry, M. Shanklin, and H. Johnson, "Dairy shelter design based on milk production decline as affected by temperature and humidity," Transactions of the ASAE, vol. 7, no. 3, pp. 329-0331, 1964.
[68] R. M. Hyde, M. J. Green, C. Hudson, and P. M. Down, "Factors associated with daily weight gain in preweaned calves on dairy farms," Preventive Veterinary Medicine, vol. 190, p. 105320, 2021.
[69] N. De Ridder, O. Sanogo, M. Rufino, H. Van Keulen, and K. Giller, "Milk: the new white gold? Milk production options for smallholder farmers in Southern Mali," Animal, vol. 9, no. 7, pp. 1221-1229, 2015.
[70] D. Rojas, "Ganancia de peso vivo de terneros lactantes criados bajo dos sistemas de crianza y alimentación, Molinopampa, Perú," Revista de investigación Agropecuaria Science and Biotechnology, vol. 3, no. 1, pp. 30-38, 2023.
[71] J. A. Elizondo-Salazar and L. R. Zumbado-Alpízar, "Efficacy of a colostrum substitute on passive immunity transfer in calves," Agronomía Mesoamericana, vol. 32, no. 1, pp. 249-260, 2021.
[72] J. Van Os, K. Reuscher, B. Dado-Senn, and J. Laporta, "Thermal stress impacts on calf welfare," JDS Commun, pp. 2023-0443, 2023.
[73] T. Hill, H. Bateman II, J. Aldrich, and R. Schlotterbeck, "Comparisons of housing, bedding, and cooling options for dairy calves," Journal of dairy science, vol. 94, no. 4, pp. 2138-2146, 2011.
[74] B. Dado-Senn, J. Van Os, J. Dorea, and J. Laporta, "Actively ventilating calf hutches using solar-powered fans: Effects on hutch microclimate and calf thermoregulation," JDS Communications, vol. 5, no. 1, pp. 61-66, 2024.
[75] H. R. Gevawer and A. C. Mendoza, "Weight gain and height index in calves fed with Biomilk® and Isilac® milk replacers offered by bottle or bucket," Doctoral Dissertation, Zamorano: Escuela Agrícola Panamericana, 2012.

[76] A. A. Habeeb, A. E. Gad, and M. A. Atta, "Temperature-humidity indices as indicators to heat stress of climatic conditions with relation to production and reproduction of farm animals," International Journal of Biotechnology and Recent Advances, vol. 1, no. 1, pp. 35-50, 2018.
[77] C. Dalla Vía and R. Gallego, "Weight gain of calves at their mother's feet and their subsequent evolution in breeding herds in the semi-arid zone," Semiárida, vol. 4, no. 1, pp. 130-130, 1989.
[78] L. Hidalgo, S. Callejas, M. Cauhépé, and M. Otero, "The effect of early weaning upon the liveweight gain of cows and calves," ITEA, vol. 98, no. 3, pp. 347–354, 2002.
[79] N. B. Varkanoff, M. F. Cipolini, R. A. Jocobo, D. E. Martínez, and A. Ragazzi, "Weight gain from birth to weaning in Brahman and Brangus 1/4, 3/8, and 5/8 calves from corrientes, Argentina," Revista Veterinaria, vol. 22, no. 1, pp. 60–63, 2011.