JOURNAL OF ANIMAL BEHAVIOUR AND BIOMETEOROLOGY

RESEARCH ARTICLE
Published Online: August 3, 2026
https://doi.org/10.31893/jabb.2026021

Influence of thermal comfort in housing facilities on the increase in live weight of guinea pigs (*Cavia porcellus*) in the high Andean region of Puno, Peru

Alfredo Pelayo Calatayud-Mendoza[a] | German Belizario-Quispe[a] | Edilberto Huaquisto-Ramos[a] | Ruben Herberht Mamani-Cato[b] | Martha Adela Coaquira-Yucra[b] | Julio Cesar Zeballos-Cabana[a] | Adderly Mamani-Flores[a]

[a]Universidad Nacional del Altiplano, Puno, Peru.
[b]Illpa Agricultural Experiment Station, Directorate of Research and Technological Development, National Institute of Agricultural Innovation, Puno, Peru.

Abstract The high-altitude region of Puno is characterized by a pronounced daily thermal oscillation, which poses a challenge for the production of guinea pigs (*Cavia porcellus*), a species that is highly sensitive to microclimatic variability. This study analyzed the association between the thermal conditions of the houses and the weight gain of guinea pigs, considering both the mean level of the Temperature-Humidity Index (THI) and its intraday stability, measured by the thermal amplitude THI. The research followed a quantitative, non-experimental and longitudinal design, using productive and environmental data from INIA's Illpa Experimental Center. A total of 36 Peru breed guinea pigs housed in three pre-existing and independent facilities were evaluated, with weight records collected every 14 days between November 2023 and February 2024 (216 observations). The climatic variables were monitored by digital sensors that recorded measurements every 15 minutes. The results show that a higher intraday thermal amplitude of the Temperature and Humidity Index (THI) is negatively and statistically significantly associated with weight gain. On the other hand, no statistically significant association was detected between the mean level of the THI and weight gain under the observed conditions. This result does not imply the absence of a possible biological effect of the average THI, but rather that this effect could not be statistically identified within the thermal range and the period analyzed. Likewise, males showed greater weight gains than females, while the estimated coefficient for age was negative, although it did not reach statistical significance in the linear mixed model. Overall, the results suggest that intraday thermal stability may be related to productive performance; however, they do not allow us to conclude that it is more important than the average level of the THI or that it constitutes the only determining factor of weight gain ($p<0.001$).

Keywords: thermal amplitude, thermal comfort, guinea pigs, housing units, high-altitude zone

1. Introduction

The high Andean region of Puno is characterized by low night temperatures and relatively higher temperatures during the day, which generates a marked daily thermal oscillation (Bradley et al., 2006; Cheng et al., 2024; Pepin et al., 2015; Vuille et al., 2018). These conditions represent a challenge for animal production, especially in species sensitive to abrupt environmental changes, because heat stress can alter metabolic and productive processes (Collier et al., 2019; West, 2003). In this context, the breeding of guinea pigs (*Cavia porcellus*) constitutes an activity of economic and nutritional importance in the family and semi-intensive systems of the Andes (Bryden, 2012; Chauca, 1997; Sánchez-Macías et al., 2018). However, their growth may be conditioned by the thermal variability of the environment and by the physiological responses associated with thermoregulation (Chavez-Tapia & Avilés-Esquivel, 2022; Powell et al., 2020; Renaudeau et al., 2012).

Maintaining adequate thermal conditions is relevant for guinea pig growth, as exposure to cold, heat, or sharp fluctuations can increase energy expenditure for body maintenance and reduce the energy available for weight gain (Mount, 1979; Renaudeau et al., 2012). In intensive and semi-intensive rearing systems, the characteristics of the houses influence ventilation, heat retention and protection from external weather conditions (Bosman & Whitfield, 2014; Chavez-Tapia & Avilés-Esquivel, 2022). However, there is limited empirical evidence on the relationship between the microclimate of the facilities and the productive performance of guinea pigs in high Andean conditions.

The Temperature and Humidity Index (THI) integrates air temperature and relative humidity and is used as an indicator of thermal conditions in animal production studies (Bohmanova et al., 2007; Thom, 1959). The literature suggests that animals can present a range of comfort within which growth is favored, while inferior or superior conditions can generate stress and reduce productive efficiency (Hahn, 1999; Jahuira Arias et al., 2022; Kadzere et al., 2002; West, 2003). In guinea pigs, a possible

Received: April 13, 2026 | Accepted: July 25, 2026

nonlinear response to thermal conditions has also been proposed; however, the identification of an optimal range depends on the environmental and productive characteristics of each breeding system (NSW, 2023; Renaudeau et al., 2012; Silanikove, 2000).

In addition to the average level of THI, its intraday variability can provide information on the thermal changes experienced by the animals. The thermal amplitude, defined as the difference between the daytime and nighttime THI, allows us to characterize the fluctuations of the microclimate between both periods. These variations can affect thermoregulation and energy use, particularly in regions with pronounced changes between day and night (Mount, 1979; Renaudeau et al., 2012). In addition, weight gain can vary depending on gender, age and infrastructure characteristics, so these factors should be analysed in conjunction with thermal conditions (Cheng et al., 2024; Mader et al., 2010; Nienaber & Hahn, 2007).

The objective of this study was to analyze the association between the thermal conditions of the sheds and the weight gain of guinea pigs (*Cavia porcellus*) in the high Andean region of Puno. To this end, the mean level of the THI, its quadratic term and the intraday thermal amplitude were considered, together with biological variables of the animals and characteristics of the sheds. The study provides evidence obtained under real management conditions on the relationship between the microclimate of the facilities and the productive yield, without assuming that the observed associations represent isolated causal effects.

2. Method and Materials

The study does not correspond to an experimental design, since the sheds and breeding ponds were pre-existing structures at the beginning of the research and no random assignment or deliberate manipulation of environmental conditions was carried out. The thermal and productive variables were observed and recorded in real management conditions at the Illpa Experimental Center of INIA, taking advantage of the natural variability of the microclimate present in each shed. In this framework, the research adopts a non-experimental and observational approach, aimed at analyzing the association between thermal conditions and weight gain of guinea pigs, without direct intervention of the researcher, in accordance with the methodological guidelines established for observational studies in applied sciences (Angrist & Pischke, 2009; Hernández-Sampieri et al., 2014; Rosenbaum, 2010).

The guinea pigs evaluated belonged to the Peru breed and, during the initial phase, the pups remained with their mothers in the maternity pools of each shed. After weaning, the animals were transferred and assigned to breeding ponds within the same shed, following the structure presented in Figure 1 and in accordance with the usual management procedures of the INIA Illpa Experimental Center. Likewise, the males were separated from the females in accordance with the routine breeding practices implemented by the institution.

In the three sheds evaluated, feeding, sanitation and management practices were exclusively developed under the institutional livestock protocols of the INIA Illpa Experimental Center. All animals received a uniform diet, the same sanitary scheme, constant veterinary care and standardized feeding schedules. The research was not experimental, since the sheds and breeding ponds were pre-existing structures and were not designed, modified or controlled for experimental purposes. Similarly, no random assignment of the animals or deliberate manipulation of the productive or environmental conditions was carried out.

The sheds are organized in an almost linear way, which favors a relatively similar exposure to external climatic conditions. However, as they are pre-existing infrastructures, each shed represents a particular combination of construction materials, type of floor and roof, ventilation, internal height and insulation. Because these characteristics were not independently manipulated and the animals were not randomly assigned, thermal variables may be related to the design of the houses and other environmental factors not observed. Consequently, the estimates should be interpreted as conditional associations to the variables included in the model and not as isolated causal effects of the thermal amplitude or of each component of the infrastructure.

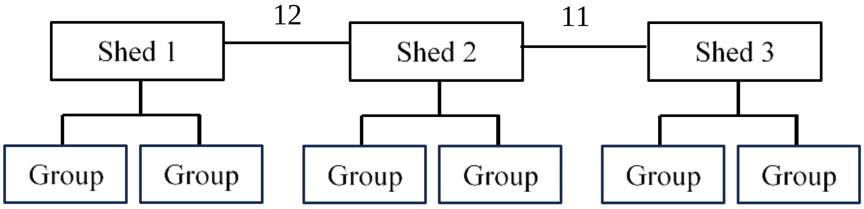

Figure 1 Structure of existing sheds and breeding pools for guinea pigs.

Note: Authors' elaboration based on the physical structure observed at the Illpa Experimental Center of the National Institute of Agrarian Innovation (INIA).

The study was developed under an observational longitudinal design, considering three pre-existing sheds, each with two breeding ponds and six guinea pigs per pool, adding up to a total of 36 animals. Each guinea pig was monitored individually, recording its weight every 14 days using a digital scale, with measurements made by specialized personnel from the National Institute of Agrarian Innovation (INIA).

The three sheds were selected because they constituted the totality of the facilities of the Illpa Experimental Center that, during the study period, housed guinea pigs of the Peruvian breed under comparable conditions of feeding, sanitary management and weighing frequency. Therefore, their selection was determined by the availability of pre-existing infrastructures and not by a random sampling of facilities. This condition limits the generalizability of the results and the ability to independently estimate the effect of the type of house.

The sample size was determined by the totality of the Peruvian breed animals that met the inclusion criteria and were available in the six housing units during the study period. Due to the observational nature of the research and the pre-existing availability of animals and facilities, no experimental sample size assignment was performed. The six measurements made per animal allowed 216 longitudinal observations to be gathered; however, the biological sample consisted of 36 animals, so the 216 measurements should not be interpreted as biologically independent observations.

For weighing, each animal was individually removed from its housing unit and handled by trained personnel from the Illpa Experimental Center. The animals remained outside the pool only for as long as necessary to record their weight and were returned immediately afterwards, in an effort to reduce the stress associated with handling. Before each weigh-in day, the digital scale was placed on a stable surface and set to zero. No additional information was available on the make, model, accuracy of the equipment or the exact timing of the measurements, which constitutes a limitation of the methodological record.

From these measurements, a longitudinal panel database comprising six observation periods was constructed, resulting in 216 repeated observations (36 guinea pigs × 6 measurement periods). The study was conducted between November 10, 2023, and February 13, 2024, allowing the evaluation of changes in body weight over time and their association with the thermal conditions recorded in the housing facilities under routine management conditions, without any intervention by the researchers. The physical characteristics and geographic location of the three evaluated housing facilities are summarized in Table 1, highlighting differences in construction materials, flooring, roofing, ventilation systems, and thermal insulation, all of which may contribute to variations in the internal microclimate experienced by the animals.

Table 1 Physical conditions and spatial location of the evaluated sheds.

Shed	Physical characteristics	Latitude (S)	Length (O)
1	Compacted earth soil; adobe walls; calamine roof; natural side ventilation; There is no additional thermal insulation.	15°43’45" S	70°09’30" W
2	Concrete floor; adobe walls; calamine roof with plastic coating; Natural ventilation both front and side.	15°43’46" S	70°09’29" W
3	Concrete floor; brick walls; calamine roof; greater internal height, better air circulation and permanent natural ventilation.	15°43’47" S	70°09’28" W

Note: Authors' elaboration based on the physical structure observed at the Illpa Experimental Center of the National Institute of Agrarian Innovation (INIA).

To record climate variables, digital data loggers (environmental sensors) were used to measure air temperature (°C) and relative humidity (%), following procedures commonly used in microclimate studies in livestock buildings (Seedorf et al., 1998; Wathes et al., 2008). The data loggers were placed at the level of each pool, close to the animals, to capture in a representative way the internal microclimate of the house, in accordance with the methodological recommendations for environmental measurement in animal production facilities. Measurements were made continuously every 15 minutes, 24 hours a day, throughout the study period from November 10, 2023 to February 13, 2024, a common practice in heat stress studies and environmental assessment in livestock systems (Brown-Brandl et al., 2005; Eigenberg et al., 2005; Mader et al., 2010).

The sensors were not independently calibrated prior to the study. The devices were used in accordance with the manufacturer's technical specifications and the declared margins of accuracy for temperature and relative humidity were considered. The absence of an independent calibration constitutes a possible source of uncertainty in the measurement of environmental variables and, therefore, a limitation of the study.

From the air temperature and relative humidity records, the Temperature and Humidity Index (THI) was calculated, obtaining daily average values, as well as differentiated averages for the day and night periods. The daytime period was defined between 08:00 and 17:00 hours, while the nighttime period comprised the remaining interval. These indicators allowed to characterize the average level of the thermal environment and its intraday variability within the houses, and were subsequently used to analyze the association between thermal conditions and the weight gain of guinea pigs between consecutive measurements. The estimation of the Temperature and Humidity Index was made from the temperature and relative humidity records using the traditional expression of the THI widely used in heat stress studies in production animals (Bohmanova et al., 2007; Mader et al., 2010; Thom, 1959).

The estimation of the Temperature and Humidity Index (THI) was made using the following expression:

$$THI = T - (0.0055.HR)(T - 14.5)$$

where represents the air temperature expressed in degrees Celsius and corresponds to the relative humidity expressed as a percentage $T(°C)HR$.

Subsequently, from the continuous records of temperature and relative humidity, the mean values of the day and night THI were calculated, with the aim of capturing the intraday thermal variability to which the guinea pigs were exposed inside the sheds. This differentiation makes it possible to evaluate not only the average level of thermal comfort, but also the fluctuations between day and night, characteristics of production systems exposed to high thermal amplitude and constitute a relevant source of physiological stress that affects production performance (Hahn, 1999; West, 2003). Several studies have shown that thermal instability, higher than the average temperature level, can reduce production efficiency and alter metabolic processes in production animals (Kadzere et al., 2002; Renaudeau et al., 2012). From these indicators, the thermal amplitude of the THI, defined as the difference between the daytime and nighttime THI, was estimated, which was incorporated into the econometric analysis as a measure of the instability of the microclimate to which the animals were exposed. The thermal amplitude of the THI was calculated using the following expression:

$$A_{THI,tj} = THI_{diurno,tj} - THI_{nocturno,tj}$$

where represents the intraday thermal amplitude of the THI recorded during the period in the housing unit.$A_{ITH,tj}tj$

Due to the longitudinal and hierarchical structure of the data, a mixed linear model was estimated as the main specification. Each guinea pig was evaluated in six periods, so repeated measurements corresponding to the same animal cannot be considered independent. The mixed model allows the explanatory variables to be incorporated as fixed effects and to control the dependence between the observations by means of a random intercept per animal. Likewise, panel data models were estimated as complementary specifications, since they allow the cross-sectional dimension (guinea pigs) and the temporal dimension (measurement periods) to be analyzed together, taking advantage of the intra- and inter-individual variability of the information and controlling for the unobserved heterogeneity constant over time (Hsiao, 2007; Baltagi, 2021). Thus, the MCO, fixed-effect, and random-effects models were used to assess the stability of the signs and magnitudes of the coefficients, while the linear mixed model was considered the main specification because it recognized the correlation between repeated measurements of the same animal.

Let be the weight gain (in grams) of the guinea pig in the period. The econometric model is specified as:$\mathit{\Delta}P_{it}it$

$$\mathit{\Delta}P_{it} = \beta_0 + \beta_1 THI_{it} + \beta_2 THI_{it}^2 + \beta_3 Sexo_i + \beta_4 Edad_{it} + \beta_5 A_{it} + \gamma_2 Galpon_i + u_i + \lambda_t + \varepsilon_{it}$$

Where:

- THI_{it}: Temperature-humidity index (average period).
- THI_{it}^2: quadratic term of the THI, incorporated to explore a possible nonlinear relationship.
- $Sexo_i$: indicator (1=male, 0=female).
- $Edad_{it}$: Age of the guinea pig (days).
- A_{it}: intraday thermal amplitude of the THI, calculated as the difference between the daytime and the nighttime THI: Shed mannequins (reference: shed 1).$Galpon_i$
- u_i: unobserved heterogeneity of guinea pig (individual effect).
- λ_t: effects of the period (time).
- ε_{it}: idiosyncratic error term.

The linear mixed model was specified as follows:

$$\Delta P_{tij} = \beta_0 + \beta_1 THI_{tj} + \beta_2 THI_{tj}^2 + \beta_3 Sexo_{ij} + \beta_4 Edad_{tij} + \beta_5 A_{tj} + \gamma_2 Galp\acute{o}n2_j + \gamma_3 Galp\acute{o}n3_j + \lambda_t + b_j + u_{ij} + \varepsilon_{tij}$$

where represents the weight gain, expressed in grams, of the animal, housed in the unit, during the period; corresponds to the average value of the Temperature and Humidity Index recorded in the unit during the period; it is its quadratic term, incorporated to explore a possible nonlinear relationship; it is an indicator variable that takes the value of 1 for males and 0 for females; it represents the age of the animal in days; corresponds to the intraday thermal amplitude of the THI; and they are indicator variables of sheds 2 and 3, considering shed 1 as a reference category; represents the fixed effects of measurement periods; it represents the animal-specific random intercept and controls the correlation between its repeated measurements; and it is the residual error.

$$\Delta P_{ijt} ijtITH_{jt}jtITH_{jt}^2 Sexo_{ij} Edad_{ijt} A_{ITH,jt} G_{2j} G_{3j} \lambda_t u_{ij} \varepsilon_{ijt}$$
$$b_j \sim N(0, \sigma_b^2),\ u_{ij} \sim N(0, \sigma_u^2),\ \varepsilon_{tij} \sim N(0, \sigma_\varepsilon^2).$$

The estimation of the mixed linear model was based on the assumptions of linearity of fixed effects, approximate normality of residuals and random effects, homogeneity of residual variance, and conditional independence of observations once random effects have been considered. The dependence derived from repeated measurements was represented by an animal-specific random intercept. In this way, the observations corresponding to the same individual could present correlation, while conditional independence was assumed between animals once the explanatory variables and the individual random effect were considered. We also assumed that random effects were not correlated with residual errors.

The study used environmental and productive records obtained during routine management activities carried out at the Illpa Experimental Center of the National Institute of Agrarian Innovation (INIA). The execution of the study and access to the information were authorized by INIA. Due to its observational nature, no additional experimental procedures or interventions other than usual animal handling practices were performed. Throughout the study period, the institutional protocols for animal management and welfare established by the Illpa Experimental Center were respected.

3. Results

Figure 2 shows the growth curves of the body weight of guinea pigs as a function of age, differentiated by house. An increasing and approximately linear trend in weight as age advances is observed in each panel, which is consistent with the biological growth pattern described for guinea pigs in controlled farming systems (Chauca, 1997; Dalle Zotte, 2014). However, there is also marked heterogeneity in individual trajectories within each house, reflecting differences in growth rate between animals even under similar management conditions, a phenomenon widely documented in animal production studies (Renaudeau et al., 2012). Similarly, variations in the slope of the curves between houses suggest differences in growth trajectories, which supports the need for a statistical analysis to examine the association between thermal conditions and weight gain, considering the individual characteristics of the animals and the houses (West, 2003).

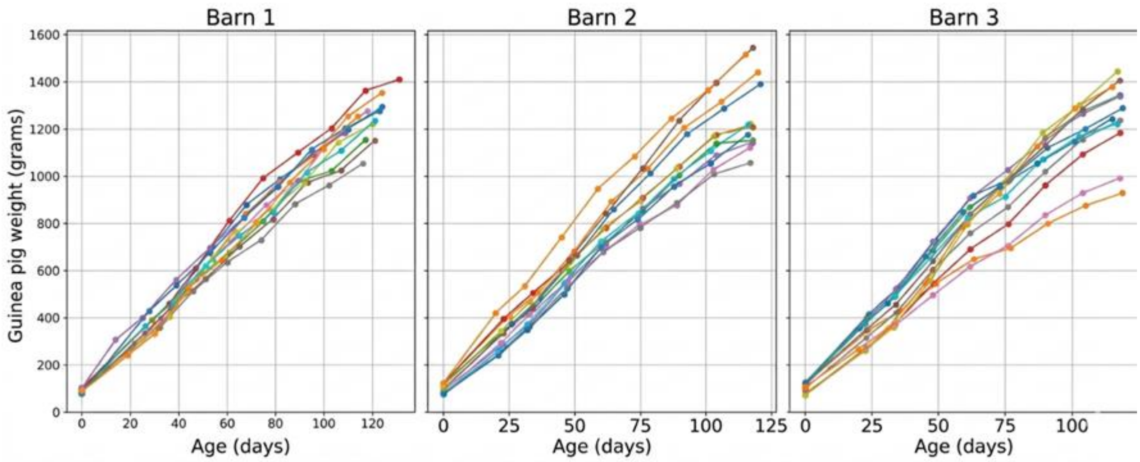

Figure 2 Guinea pig weight growth curves according to the type of house.
Note: Prepared by the authors based on the production records of the Illpa Experimental Center of the National Institute of Agrarian Innovation (INIA).

To robustly analyze the relationship between thermal comfort and weight gain, four complementary specifications were estimated: ordinary least squares (OQs), fixed period effects, random panel effects, and a linear mixed model. The linear mixed model was considered the main specification because it recognizes the longitudinal structure of the information, made up of six repeated measurements within each animal. MCO and panel models were used as complementary sensitivity analyses to assess the stability of the signs and the magnitudes of the estimated coefficients, following the traditional approaches of econometric analysis of panel data (Baltagi, 2021; Greene, 2018; Hsiao, 2014).. In all the specifications, the Temperature and Humidity Index (THI) and its quadratic term, sex, age, intraday thermal amplitude of the THI, the type of shed and the measurement periods were incorporated. The results are presented in Table 2, based on a sample of 216 observations.

Diagnostic analyses showed no substantial deviations from the model assumptions. The residuals had an approximately symmetrical distribution and the quantile-quantile graph did not show significant deviations from normality. Likewise, the dispersion of the residuals against the adjusted values did not show systematic patterns that indicated relevant problems of heteroskedasticity. The sensitivity analysis, based on the successive exclusion of animals and housing units, showed that the signs and magnitudes of the main coefficients remained stable. Although some observations with relatively high studentized residuals were detected, their exclusion did not substantially modify the results or the main conclusions of the study.

The joint test applied to the fixed period effects did not allow the rejection of the null hypothesis that their coefficients were jointly equal to zero ($F = 1.47$; $p = 0.203$). Therefore, once the variables included in the model were considered—mean THI, its quadratic term, intraday thermal amplitude, sex, age, and type of house—no statistically significant differences were detected between the measurement periods. This result does not demonstrate the absence of temporal variation in weight gain, but indicates that such variation could not be statistically identified in the sample analyzed.

Ordinary least squares, period-fixed effects, and random-effects models were used as supplementary specifications to examine the stability of the signs and the magnitudes of the estimated coefficients. Consequently, the substantive interpretation of the results was based on the mixed linear model, which allows the correlation between repeated measurements corresponding to the same animal to be represented.

The linear mixed model was considered the main specification because it represents the longitudinal structure of the data, made up of six repeated measurements in each of the 36 animals. The incorporation of a specific random intercept for each animal makes it possible to control the correlation between the observations corresponding to the same guinea pig and to recognize that their repeated measurements are not independent. The MCO and panel models were presented as complementary analyses, while the substantive interpretation was mainly based on the mixed linear model. In this way, standard errors and significance tests recognize the lack of independence between observations belonging to the same hierarchical level. The MCO and panel models are presented as complementary analyses, while the substantive interpretation is mainly based on the linear mixed model.

Table 2 Estimation of the association between thermal comfort and weight gain of guinea pigs using MCO, fixed period effects, random panel effects, and linear mixed model.

Variables	MCO	Fixed period effects	Panel Random Effects	Mixed linear model
Intercept	-128.7960	-1142.5005	-1070.1	349.65
	(3114.396)	(4613.048)	(4707.3)	(69.92)
THI	16.6922	47.0788	44.733	1.672
	(101.159)	(149.110)	(152.17)	(1.427)
THI Square	-0.1112	-0.3709	-0.3518	-0.366
	(0.823)	(1.213)	(1.2382)	(0.984)
Sex (1=male; 0=female)	29.3729***	29.2588***	29.258***	29.259***
	(3.983)	(5.129)	(5.0681)	(4.139)
Age in days	-0.8620***	-0.7539*	-0.7533*	-0.754
	(0.096)	(0.451)	(0.4459)	(0.622)
Thermal amplitude of the THI	-14.8374***	-8.3824**	-8.4095**	-8.389**
	(2.325)	(3.594)	(3.6049)	(3.462)
Type of house				
Shed 2	1.8386	2.4234	2.4120	2.421
	(1.8386)	(4.166)	(4.1226)	(5.229)
Shed 3	2.2806	0.7553	0.7787	0.761
	(5.095)	(6.853)	(6.7840)	(5.461)
R squared	0.555	0.570	0.5777	
R squared marginal				0.5723
Conditional squared R				0.5846
F	37.01***	37.65***	23.142***	24.053***
Number of observations	216	216	216	216

Note: The values in parentheses correspond to robust standard errors in the MCO and panel specifications, and to model-based standard errors in the mixed linear specification. p < 0.01; ** p < 0.05; * p < 0.10. Shed 1 is the reference category. *Source:* Prepared by the authors based on the productive and environmental records of the Illpa Experimental Center of the National Institute of Agrarian Innovation (INIA).

In the linear mixed model, sex presented a positive and statistically significant association at 1%, which indicates that males registered, on average, a weight gain 29,259 grams greater than females, keeping the other variables constant. Likewise, the intraday thermal amplitude of the THI presented a negative and significant association at 5%; Its coefficient of −8.389 indicates that the increase of one unit in this variable is associated with an approximate decrease of 8,389 grams in weight gain.

The age coefficient was negative in all four specifications. However, in the mixed linear model, considered as the main specification, this association did not reach statistical significance. Therefore, the estimated sign suggests a possible slowdown in weight gain with age, but the evidence from the main model does not allow to statistically confirm this relationship.

In the linear mixed model, the coefficients for the mean Temperature–Humidity Index (THI) and its quadratic term were not statistically significant. Therefore, within the observed range of thermal conditions, no statistically significant linear or nonlinear association was detected between mean THI and weight gain. This finding should not be interpreted as evidence that the average thermal environment has no biological effect; rather, it indicates that the available data did not provide sufficient statistical power to identify such an association under the conditions evaluated. For descriptive purposes, Figure 3 presents the average body weight of guinea pigs according to sex. As shown, males exhibited a higher average body weight (1244.3 g) than females (1065.0 g), a pattern that is consistent with the positive and statistically significant coefficient estimated for sex in the mixed linear model.

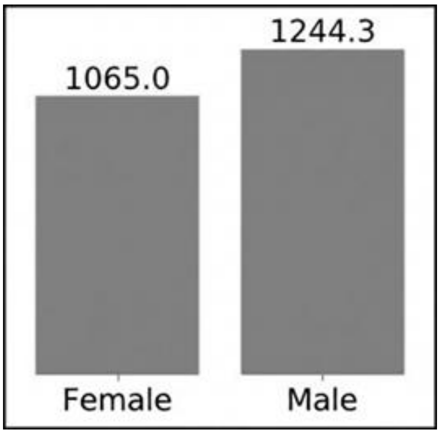

Figure 3 Descriptive comparison of average body weight of guinea pigs by sex.
Note: Values represent the mean body weight (g) recorded during the study period. Prepared by the authors based on the production records of the Illpa Experimental Center of the National Institute of Agrarian Innovation (INIA).

Figure 4 presents, for descriptive purposes, the observed relationship between mean THI and guinea pig weight gain, together with a quadratic fit. Visually, the estimated curve suggests a possible nonlinear relationship; however, the linear and quadratic coefficients of the THI were not statistically significant. Therefore, there is insufficient evidence to confirm the presence of an optimal level of THI or an inverted U-shaped relationship under the conditions analyzed.

Consequently, the fit depicted in the figure should be interpreted as an exploratory description of the data and not as a demonstration of a nonlinear biological response. The lack of significance may be related to the relatively narrow range of THI observed, sample size, or variability between animals and housing units. Studies with greater thermal variation and an experimental design would allow this possible relationship to be evaluated more precisely.

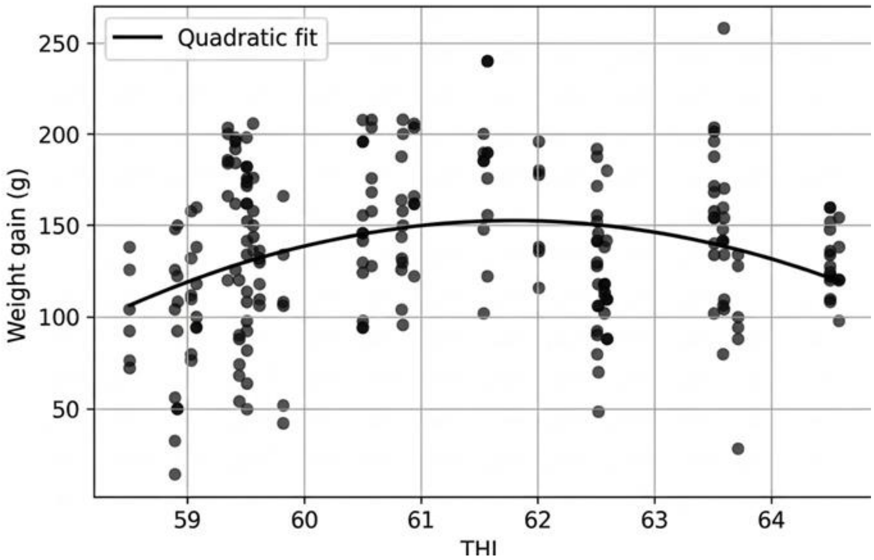

Figure 4 Observed relationship between the Temperature and Humidity Index (THI) and guinea pig weight gain.

The coefficients associated with the type of house were not statistically significant after controlling for thermal variables and individual characteristics of the animals. However, this result does not mean that infrastructure is unimportant, as building materials, type of floor and roof, ventilation and insulation can modify the indoor microclimate. On the other hand, the thermal amplitude of the THI showed a negative and statistically significant relationship with weight gain ($p < 0.05$). Therefore, this effect must be interpreted in a conditional manner, without considering that thermal stability is the only factor that determines production performance.

Taken together, the results show a statistically significant association between the intraday thermal amplitude of the THI and weight gain. In contrast, no statistically significant associations were detected for the mean THI or for the indicator variables of the house. These differences in significance do not allow us to conclude that the mean THI or infrastructure is not biologically important, but only that their associations could not be statistically identified under the conditions studied.

4. Discussion

Under the conditions analyzed, no statistically significant association was detected between mean THI level and weight gain. This result does not constitute evidence of the absence of a biological effect of the average thermal environment, but rather indicates that such an effect could not be statistically distinguished within the observed THI range. Average values can mask episodes of stress linked to daily fluctuations, as West points out (2003), Bohmanova et al. (2007) and Mader et al. (2010); however, the results of the present study do not allow us to establish that the thermal amplitude replaces or is necessarily more important than the mean level of the THI.

In guinea pigs, Jahuira Arias et al. (2022) They support that moderate ranges of temperature and humidity do not necessarily translate into productive improvements if the animal suffers sudden changes between day and night. This pattern has also been documented in studies on heat stress in production animals, where intraday thermal variability can affect thermoregulation and energy metabolism (Collier et al., 2019; Renaudeau et al., 2012). Taken together, these findings reinforce the interpretation that the average THI, by itself, does not fully capture the relevant heat stress in high Andean systems, where daily thermal amplitude constitutes a critical component of the productive environment.

The inclusion of the quadratic term of the THI allowed us to explore a possible nonlinear relationship between the thermal environment and weight gain. Although the estimated sign is compatible with the hypothesis of an inverted U-shaped curve, the coefficient was not statistically significant; therefore, the data do not confirm the existence of an optimal level of THI. However, this functional form is consistent with the theory of animal thermal comfort, according to which there may be a range of environmental conditions favorable for growth, while lower or higher values can generate thermal stress Thom (1959), West (2003), Mader et al. (2010) and Renaudeau et al. (2012) Likewise, possible nonlinear responses to changes in temperature and humidity have been described in guinea pigs and other production animals (NSW, 2023; Collier et al., 2019; Dikmen & Hansen, 2009). The lack of statistical significance observed in this study could be related to the concentration of THI values within a relatively narrow thermal range, although sample size and variability between animals and housing units may also play a role.

The intraday thermal amplitude of the THI showed a negative and statistically significant association with weight gain, constituting one of the main findings of the study. This result provides evidence that thermal fluctuations may be related to productive performance under the conditions analyzed. From a biological perspective, Mount (1979) He argues that thermal fluctuations can increase the energy expenditure allocated to thermoregulation and reduce the energy available for growth. Similarly, (Renaudeau et al. (2012), Kadzere et al. (2002), Mader et al. (2010) They point out that intraday thermal variability can generate accumulated physiological stress and affect production efficiency. Likewise, Chauca (1997) and Jha et al. (2019) highlight the relevance of stable environmental conditions for the performance of production animals. These antecedents support the biological plausibility of the observed association; however, the lack of statistical significance of the mean THI does not allow us to conclude that the thermal amplitude is biologically more important or that the mean level of the environment is without effect.

The THI and highly significant effect of sex indicates that males have greater weight gains than females, a result widely documented in the literature on guinea pig production. Chauca (1997) He points out that males have a higher growth rate due to hormonal and metabolic differences that favor the deposition of body mass. Constantly, from the Dalle Zotte (2014) and New South Wales (NSW, 2023) Greater weight gains are reported in males under different breeding systems, even when handling and feeding conditions are homogeneous. Similarly, Lebas et al. (1997) confirm that sex is one of the most robust biological determinants of growth in small production mammals, which validates the inclusion of this variable as an individual control in the econometric model and supports the magnitude of the estimated effect (Powell et al., 2020).

The negative age coefficient is compatible with a possible slowdown in weight gain as animals advance towards maturity. This pattern coincides with what Chauca (1997) described, who notes that guinea pig growth is most accelerated during the early stages after weaning and decreases as the animals approach maturity. Similarly, (Powell et al., 2020; Seedorf et al., 1998) They point out that production efficiency and weight gain can be progressively reduced with age in production animals. However, in the present study, the association between age and weight gain was not statistically significant in the linear mixed model. Therefore, the negative coefficient should be interpreted as an estimated standard compatible with the literature, but not as a conclusive result of the study.

As for the infrastructure, the lack of statistical significance of the indicator variables of the shed does not allow us to conclude that its physical characteristics are irrelevant. Each facility is simultaneously differentiated by the materials of the walls, floor, ceiling, ventilation, internal height and insulation, factors that can jointly modify the microclimate to which the animals were exposed. Because these characteristics did not vary independently, it is not possible to accurately identify the specific contribution of each structural component or to determine whether the estimated association for thermal amplitude corresponds exclusively to the variability of the THI or partially reflects the joint effect of the house design and other unmeasured environmental factors.

From an operational approach, the relationship between the thermal environment and guinea pig growth can be summarized by synthetic indicators such as the Temperature and Humidity Index (THI), which integrates information on environmental temperature and relative humidity, and has been widely used in studies on heat stress in livestock species (Bohmanova et al., 2007; Thom, 1959). The literature indicates that moderate levels of THII favor body growth, while high or very low values generate heat stress and reduce production efficiency (Collier et al., 2019; Jahuira Arias et al., 2022; Kadzere et al., 2002; Renaudeau et al., 2012). In guinea pigs, this relationship is not usually strictly linear, suggesting the existence of an optimal range of thermal comfort for weight gain, especially under controlled and semi-intensive management systems (Jahuira Arias et al., 2022; NSW, 2023; Renaudeau et al., 2012).

An important limitation of the study is the possible confusion between the structural characteristics of the sheds and the thermal variables recorded. The three sheds evaluated were pre-existing infrastructures and differed simultaneously in construction materials, floor, roof, ventilation, internal height, and insulation. Consequently, although the thermal amplitude of the THI maintained a negative and statistically significant association with weight gain after controlling for the observed variables, the observational design does not allow attributing this relationship exclusively to thermal stability or completely separating its influence from that corresponding to the design of the houses and other unmeasured environmental factors. The shed indicator variables control for average differences between the installations, but do not allow the individual effect of each construction characteristic to be identified. Therefore, the results should be interpreted as associations and require validation by experimental studies that include a greater number of houses and controlled structural modifications.

5. Conclusions

The results show that a higher intraday thermal amplitude of the THI is associated with a lower weight gain of guinea pigs under the conditions analyzed, while the mean level of the THI does not present a statistically significant association. However, the observed relationship cannot be attributed exclusively to thermal stability, because the sheds differ simultaneously in their construction materials, ventilation, floor, roof, internal height and insulation. Therefore, the results should be interpreted as associations conditioned by the observed characteristics and not as isolated causal effects. Likewise, males showed greater weight gains than females, while the estimated coefficient for age was negative, although it did not reach statistical significance in the linear mixed model.

From a productive and management perspective, the results suggest that intraday thermal stability may be associated with the productive performance of guinea pigs. However, because only three pre-existing sheds were evaluated, whose construction characteristics varied simultaneously, it is not possible to independently estimate the effect of each type of infrastructure or causally attribute the observed differences to ventilation, materials or insulation. Therefore, the recommendations aimed at reducing the thermal amplitude should be considered preliminary and require validation through experimental studies with a greater number of installations and controlled structural modifications.

6. Declarations

6.1. Ethical considerations

This research was based on a non-experimental observational study conducted under routine husbandry conditions at the Illpa Experimental Center of the National Institute of Agrarian Innovation (INIA), Peru. No experimental manipulation, invasive procedures, or interventions beyond routine animal management were performed. All animal handling complied with the institutional animal welfare protocols and internationally accepted animal welfare principles (CIOMS and OIE). Owing to the purely observational nature of the study, formal ethical approval for animal experimentation was not required.

6.2. Use of artificial intelligence (AI)

The authors declare that no generative artificial intelligence (AI) tools were used in the preparation, analysis, or writing of this manuscript.

6.3. Conflict of interest

The authors declare that they have no conflict of interest.

6.4. Funding

The research was financed by the Special Fund for University Development (FEDU) through the Office of the Vice-Rector for Research of the National University of the Altiplano – Puno, within the framework of its programs to support scientific research.

References

Angrist, J. D., & Pischke, J.-S. (2009). *Mostly harmless econometrics*. Princeton University Press. https://doi.org/10.1515/9781400829828

Baltagi, B. H. (2021). *Econometric analysis of panel data* (6th ed.). Springer International Publishing. https://doi.org/10.1007/978-3-030-53953-5

Bohmanova, J., Misztal, I., & Cole, J. B. (2007). Temperature-humidity indices as indicators of losses in milk production due to heat stress. *Journal of Dairy Science, 90*(4), 1947–1956. https://doi.org/10.3168/jds.2006-513

Bosman, G., & Whitfield, C. (2014). Perceptions of vernacular architecture. In *Vernacular architecture: Toward a sustainable future* (pp. 157–162). https://doi.org/10.1201/b17393

Bradley, R. S., Vuille, M., Diaz, H. F., & Vergara, W. (2006). Threats to water supply in the tropical Andes. *Science, 312*(5781), 1755–1756. https://doi.org/10.1126/science.1128087

Brown-Brandl, T. M., Eigenberg, R. A., Nienaber, J. A., & Hahn, G. L. (2005). Indicators of dynamic response to heat stress in shaded and unshaded feeder cattle, Part 1: Analysis of indicators. *Biosystems Engineering, 90*(4), 451–462. https://doi.org/10.1016/j.biosystemseng.2004.12.006

Bryden, W. L. (2012). Mycotoxin contamination in the feed supply chain: Implications for animal productivity and feed safety. *Animal Feed Science and Technology, 173*(1–2), 134–158. https://doi.org/10.1016/j.anifeedsci.2011.12.014

Chauca, L. (1997). *Production of guinea pigs (Cavia porcellus)* (L. Chauca de Zaldívar, Ed.). Food and Agriculture Organization of the United Nations. https://archive.org/details/bub_gb_VxLVzsZ5HWcC/page/n87/mode/2up

Chavez-Tapia, I., & Avilés-Esquivel, D. (2022). Characterization of the guinea pig production system of the Mocha canton, Ecuador. *Revista de Investigaciones Veterinarias del Perú, 33*(2), e22576. https://doi.org/10.15381/rivep.v33i2.22576

Cheng, Q., Wang, H., Xu, X., He, T., & Chen, Z. (2024). Indoor thermal comfort sector: Review of detection and control methods for the thermal environment in livestock buildings. *Sustainability, 16*(4), Article 1662. https://doi.org/10.3390/su16041662

Collier, R. J., Baumgard, L. H., Zimbelman, R. B., & Xiao, Y. (2019). Heat stress: Physiology of acclimatization and adaptation. *Animal Frontiers, 9*(1), 12–19. https://doi.org/10.1093/af/vfy031

Dalle Zotte, A. (2014). Breeding rabbits for carnivorous purposes. *Animal Frontiers, 4*(4), 62–67. https://doi.org/10.2527/af.2014-0035

Dikmen, S., & Hansen, P. J. (2009). Is the temperature-humidity index the best indicator of heat stress in lactating dairy cows in a subtropical environment? *Journal of Dairy Science, 92*(1), 109–116. https://doi.org/10.3168/jds.2008-1370

Eigenberg, R. A., Brown-Brandl, T. M., Nienaber, J. A., & Hahn, G. L. (2005). Dynamic indicators of heat stress response in shaded and unshaded feedlot cattle, Part 2: Predictive relationships. *Biosystems Engineering, 91*(1), 111–118. https://doi.org/10.1016/j.biosystemseng.2005.02.001

Greene, W. H. (2018). *Econometric analysis* (M. Reynolds, Ed., 5th ed.). Pearson Education Limited.

Hahn, G. L. (1999). Dynamic responses of cattle to thermal loads. *Journal of Animal Science, 77*(Suppl. 2), 10. https://doi.org/10.2527/1997.77suppl_210x

Hernández-Sampieri, R., Fernández-Collado, C., & Baptista-Lucio, M. del P. (2014). *Research methodology* (6th ed.). McGraw-Hill.

Hsiao, C. (2007). Panel data analytics: Advantages and challenges. *TEST, 16*(1), 1–22. https://doi.org/10.1007/s11749-007-0046-x

Hsiao, C. (2014). *Analysis of panel data* (3rd ed.). Cambridge University Press. https://doi.org/10.1017/CBO9781139839327

Jahuira Arias, M. H., Arias Tuco, J., Díaz Garmendia, F. R., & Chauca Francia, L. J. (2022). Temperature-humidity analysis on mortality and body growth of synthetic guinea pigs (*Cavia porcellus*) in Moquegua, Peru. *Agricultural Science & Technology, 23*(1), 1–17. https://doi.org/10.21930/rcta.vol23_num1_art:2014

Jha, R., Fouhse, J. M., Tiwari, U. P., Li, L., & Willing, B. P. (2019). Dietary fiber and intestinal health of monogastric animals. *Frontiers in Veterinary Science, 6*, Article 48. https://doi.org/10.3389/fvets.2019.00048

Kadzere, C., Murphy, M., Silanikove, N., & Maltz, E. (2002). Heat stress in lactating dairy cows: A review. *Livestock Production Science, 77*(1), 59–91. https://doi.org/10.1016/S0301-6226(01)00330-X

Lebas, F., Coudert, P., de Rochambeau, H., & Thébault, R. G. (1997). *The rabbit: Husbandry, health and production* (R. D. Branckaert, Ed.). Food and Agriculture Organization of the United Nations.

Mader, T. L., Johnson, L. J., & Gaughan, J. B. (2010). A comprehensive index for assessing environmental stress in animals. *Journal of Animal Science, 88*(6), 2153–2165. https://doi.org/10.2527/jas.2009-2586

Mount, L. E. (1979). *Adaptation to the thermal environment: Man and his productive animals* (E. Arnold, Ed.).

Nienaber, J. A., & Hahn, G. L. (2007). Livestock production system management responses to thermal challenges. *International Journal of Biometeorology, 52*(2), 149–157. https://doi.org/10.1007/s00484-007-0103-x

NSW Department of Primary Industries Animal Research Review Panel. (2023). *Guidelines for the housing of guinea pigs in scientific institutions* (Issue 21). NSW Department of Primary Industries.

Pepin, N., Bradley, R., Diaz, H., Baraer, M., Cáceres, E., Forsythe, N., *et al.* (2015). Altitude-dependent warming in mountainous regions of the world. *Nature Climate Change, 5*(5), 424–430. https://doi.org/10.1038/nclimate2563

Powell, D. M., Kozlowski, C. P., Clark, J., Seyfried, A., Baskir, E., & Franklin, A. D. (2020). Physical and physiological indicators of welfare in guinea pigs (*Cavia porcellus*) that act as ambassador animals. *Animals, 10*(5), Article 815. https://doi.org/10.3390/ani10050815

Renaudeau, D., Collin, A., Yahav, S., de Basilio, V., Gourdine, J. L., & Collier, R. J. (2012). Adaptation to hot climates and strategies to alleviate heat stress in livestock production. *Animal, 6*(5), 707–728. https://doi.org/10.1017/S1751731111002448

Rosenbaum, P. R. (2010). *Design of observational studies*. Springer. https://doi.org/10.1007/978-1-4419-1213-8

Sánchez-Macías, D., Barba-Maggi, L., Morales-de la Nuez, A., & Palmay-Paredes, J. (2018). Guinea pig for meat production: Systematic review of factors affecting production, carcass quality, and meat quality. *Meat Science, 143*, 165–176. https://doi.org/10.1016/j.meatsci.2018.05.004

Seedorf, J., Hartung, J., Schröder, M., Linkert, K. H., Pedersen, S., Takai, H., Johnsen, J. O., Metz, J. H. M., Groot Koerkamp, P. W. G., Uenk, G. H., Phillips, V. R., Holden, M. R., Sneath, R. W., Short, J. L. L., White, R. P., & Wathes, C. M. (1998). A survey of ventilation rates in livestock buildings in northern Europe. *Journal of Agricultural Engineering Research, 70*(1), 39–47. https://doi.org/10.1006/jaer.1997.0274

Silanikove, N. (2000). Effects of heat stress on the welfare of extensively managed domestic ruminants. *Livestock Production Science, 67*(1–2), 1–18. https://doi.org/10.1016/S0301-6226(00)00162-7

Thom, E. C. (1959). The discomfort index. *Weatherwise, 12*(2), 57–61. https://doi.org/10.1080/00431672.1959.9926960

Vuille, M., Carey, M., Huggel, C., Buytaert, W., Rabatel, A., Jacobsen, D., Soruco, A., Villacis, M., Yarleque, C., Elison Timm, O., Condón, T., Salzmann, N., & Sicart, J.-E. (2018). Rapid snow and ice decline in the tropical Andes: Impacts, uncertainties, and challenges ahead. *Earth-Science Reviews, 176*, 195–213. https://doi.org/10.1016/j.earscirev.2017.09.019

Wathes, C. M., Kristensen, H. H., Aerts, J.-M., & Berckmans, D. (2008). Is precision livestock farming an engineer's dream or nightmare, an animal's friend or foe, and a farmer's panacea or pitfall? *Computers and Electronics in Agriculture, 64*(1), 2–10. https://doi.org/10.1016/j.compag.2008.05.005

West, J. W. (2003). Effects of heat stress on production in dairy cattle. *Journal of Dairy Science, 86*(6), 2131–2144. https://doi.org/10.3168/jds.S0022-0302(03)73803-X