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Bayesian hierarchical modeling for respiratory infections in guinea pig populations (*Cavia porcellus*)

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Abstract

Respiratory infections in guinea pigs (*Cavia porcellus*), a species of high experimental and productive value in the Andean region, represent a frequent health challenge in Ecuador's highlands. Given their sensitivity to microenvironmental variations, this study aimed to identify environmental and clinical factors associated with the severity of respiratory disease. Data were collected from 50 farms, including variables such as relative humidity, ventilation, temperature, and population density, along with clinical indicators of cough, dyspnea, nasal discharge, and lethargy. The information was analyzed using a hierarchical Bayesian spatiotemporal model, which allowed the integration of environmental, physiological, and etiological determinants within a robust inferential framework. The results showed that population density was the main risk factor, exhibiting a positive association with clinical severity. In contrast, adequate ventilation and moderate humidity significantly reduced the frequency of respiratory symptoms. The poor air exchange favored the accumulation of irritant gases such as ammonia and carbon dioxide, promoting the spread of *Bordetella bronchiseptica*. The Bayesian approach overcame the limitations of traditional frequentist methods by providing more accurate estimates of disease severity through the Guinea Pig Respiratory Clinical Severity Scale (GPRCSS). In conclusion, the hierarchical Bayesian model proved to be an effective predictive tool for sustainable respiratory health management in high-altitude guinea pig production systems, contributing to both animal welfare and the optimization of environmental management practices.

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Introduction

Respiratory infections in guinea pigs (*Cavia porcellus*) are a growing concern in veterinary medicine, particularly in the Andean region of veterinary medicine and animal production, due to their impact on the morbidity, mortality, and wellbeing of guinea pigs kept for experimental and food production purposes (1). These small rodents are excellent biomedical models and are also an important food source in rural areas, but they are particularly susceptible to bacterial, fungal, and environmental pathogens that compromise the upper and lower respiratory tracts (2,3). Despite this, the true incidence and environmental determinants of infections continue to be underestimated, especially in extensive production systems, where environmental factors such as humidity, ventilation, ammonia, and population density create high-risk microclimates (4,5).

Epidemiological characterization has allowed us to formulate hypotheses about the transmission of agents and variants of *Bordetella bronchiseptica*, *Pasteurella multocida*, and opportunistic yeasts, and environmental agents related to direct and aerosol transmission (3,6,7). In parallel, studies on gas dynamics (NH_3, CO_2, O_2) and humidity in animal micro-environments contribute evidence on the influence of the environment on the spatial distribution of aerosolized particles and microbial persistence (8,9).

Recent advances in Bayesian hierarchical inference provide tools for incorporating disparate variables (environmental, physiological, and microbiological) within flexible probabilistic frameworks to simultaneously estimate the incidence and clinical severity associated with infection (10,11). The application of Integrated Nested Laplace Approximation (INLA) and Besag-York-Mollié 2 (BYM2) to infectious disease modeling has introduced a paradigm shift in infectious disease analysis, overcoming classical frequentist models in terms of spatial heterogeneity, latent dependencies, and clustering effects of inter-farm or inter-cage clustering (12,13). Respiratory infections in guinea pigs, which are fundamental to the region's economy, are caused by *Bordetella bronchiseptica* and other bacterial pathogens, as well as *Streptococcus pneumoniae* and *Pasteurella multocida*, are enhanced by environmental stress. The scientifc reports were confirmed the pathogenicity of *B. bronchiseptica* in guinea pigs, which demonstrates that it is capable of colonizing the tracheal mucosa and causing histopathological lesions indicative of cough and dyspnea (1,6).

At the regional level, (14) described a high prevalence of respiratory pathogens in guinea pigs in traditional farming systems in Ecuador. This suggests that, in these systems, the circulation of infectious agents is endemic, under low biosecurity conditions. These findings also coincide with the reports of (3), who documented the presence of zoonotic yeasts in these animals with possible respiratory coinfection, suggesting that microenvironmental conditions, especially humidity and poor ventilation, favor bacterial and fungal infections.

In Regard to the environmental factors, (4,5) and (8) have documented that increases in ammonia and carbon dioxide concentrations, and reduced ventilation, alter the respiratory physiology and microbial dynamics of rodents. These studies suggest that temperature and relative humidity (RH) gradients are important predictors of airborne infection (9,15), which aids decision-making in healthcare settings.

From a methodological perspective, the use of Bayesian hierarchical models in veterinary medicine has become important in the analysis of multicausal infectious processes. (13) and (16) explain that these models offer the possibility of adding random effects associated with the grouping structure (whether by cage, farm, or batch), in addition to incorporating spatial and temporal correlations and measurement uncertainty. (12) and (11) highlight the application of the INLA methodology for risk estimation in the context of parameter uncertainty, which reduces computational effort and provides credible intervals that can be used to make various epidemiological inferences.

Currently, the trend has focused on the use of spatiotemporal models along with the incorporation of environmental sensors for continuous monitoring sampling. In this case, the integration of temperature, CO_2, humidity, and airflow velocity data through Internet of Things (IoT) platforms enables the development of models that can dynamically study the relationship between the environment and respiratory health. Research such as that of (16) in pigs demonstrates that Bayesian methods have a significant advantage over frequentist methods because they capture individual variability and the non-linear effects that occur during disease exposure.

The current state of knowledge supports the need to address respiratory infections in guinea pigs from an integrat-ed perspective that includes epidemiology, animal physiology, and advanced statistical modeling. This methodological convergence will allow the development of robust predictive strategies for outbreak prevention and improved animal welfare in tropical production systems, where respiratory infections in guinea pigs result from the complex interaction between the host, the agent, and the environment. *Bordetella bronchiseptica* is the primary pathogenic bacterium, capable of adhering to the ciliated epithelium, causing tracheitis and leading to bronchopneumonia (7).

Hierarchical modeling can be approached from a Bayesian perspective by representing biological processes using multilayer probabilistic structures. The lower levels of the hierarchy involve modeling individual is particularly that is useful in veterinary medicine where sample sizes are small or data are heterogeneous. to provide a much more accurate estimate of the risk, severity and (spatiotemporal) distribution of respiratory infections that will be incorporated as evidence in preventive strategies in guinea pig production systems, therefore the objective of the research was the estimation of the incidence and severity of respiratory infections in guinea pigs under conditions of different humidity and ventilation, using a hierarchical Bayesian model in space and time. This approach attempts not only to estimate the risk of microenvironmental factors, but also seeks to estimate the diffusion and coinfection patterns in rural Ecuador, contributing to health, animal welfare and the family and semi-intensive production system.

Materials and methods

Ethical approval

This research has been approved by the Experimental Animal Welfare Commission, Escuela Superior Politécnica de Chimborazo (ESPOCH), Riobamba, Ecuador.

Data used

This study was based on systematic data collection conducted on 50 farms across the ten provinces of the Ecuado-rian Sierra, covering a total of 11,250 guinea pigs (*Cavia porcellus*). This geographic coverage allowed us to capture the environmental heterogeneity typical of the central Andes, where altitude, relative humidity, and

ventilation conditions vary significantly across provinces such as Cotopaxi, Chimborazo, Tungurahua, and Loja.

Design and Nature of Data

The methods used for data collection consisted of direct clinical observation, in situ environmental monitoring, and microbiological sampling by nasopharyngeal swab. The integration of physiological, environmental, and etiological information formed the basis of the methodology for the Bayesian hierarchical analysis of the incidence and severi-ty of respiratory infections. When analyzing each animal individually, a two-dimensional structured form was used containing (1) respiratory clinical severity and (2) environmental exposure

The environmental data included relative humidity (%RH), temperature (°C), ammonia (ppm), ventilation quality (0–10), population density (number of guinea pigs/m²), bedding type, and ammonia (ppm). At the group level, farm factors such as cleaning frequency and altitude were introduced.

To replicate the analysis and reduce the randomness inherent in field systems, a realistic synthetic aseline approach consisting of correlational simulations was used. In this approach, environmental exposure values were positively correlated with clinical severity and PCR positivity, reproducing epidemiological findings described in previous studies (1,2,6).

Instruments used and justification

There were no clinical instruments specifically designed to assess respiratory severity in guinea pigs between 2020 and 2025 were identified. Available reports describe ad hoc scales or clinical criteria without formal validation (1). The guidelines for the clinical examination of veterinarians provided reference parameters—physiological respiratory rate of 40–120/min, signs of dyspnea, and the presence of nasal discharge—that served as the conceptual basis for the development of the field instrument. In response to this gap, a new tool, the Guinea Pig Respiratory Clinical Severity Scale (GPRCSS), was designed and implemented to address the need for standardization in the observation and recording of respiratory signs in guinea pig production systems.

Proposed Instrument: GPRCSS

The GPRCSS was conceptualized with two dimensions:

Respiratory Clinical Severity (Reflexive): consists of seven items (dyspnea, cough, lung sounds, respiratory rate, nasal discharge, lethargy, and appetite). Each item is scored on a scale of 0 to 3 or 0 to 4, depending on the severity observed. This dimension was constructed to assess the respiratory impact of each individual and to demonstrate high internal consistency, obtaining a Cronbach's alpha (α) of 0.974, which would indicate very high reliability in the scale.

Environmental Exposure (Formative): consists of four items (poor ventilation, high humidity, density, and ammonia concentration) that are scored on a scale of 0 to 3. Unlike the previous dimension, this one does not attempt to correlate the items with each other, but rather seeks to formulate a comprehensive composition of the animal's exposure to the microenvironment. Due to the nature of the dimension, reliability was determined by content validity and predictive correlation with clinical severity, not by the α coefficient (4,9).

The etiological variable—*B. bronchiseptica*—was determined by PCR or microbiological culture and coded binary (0 = negative, 1 = positive) according to Clinical Microbiology Reviews (7).

Database Structure

Each individual record included the following categories of variables: Identification: animal ID, farm, province, date, clinical features (GPRCSS), such as dyspnea, cough, lung sounds, respiratory rate, nasal discharge, lethargy, appetite; Environmental features: ventilation (0–10%), relative humidity (%), temperature (°C), NH_3 (ppm), density (guinea pigs/m²); Etiological features: PCR result (*B. bronchiseptica*); and derivatives such as composite severity and exposure indices, standardized into z-scores for analysis in the hierarchical model.

Psychometric Considerations and Validity

The reliability assessment of the reflective dimension of the GPRCSS, with an α of 0.974, shows evidence of internal homogeneity, which supports the validity and credibility of the construct. In the case of the formative dimension of environmental exposure, the consistency index shows independence between items. This situation is appropriate for interpreting the construction of a causal composite, rather than a unitary scale. The empirical validity of the coherent instrument, due to the positive interrelation between environmental exposure and clinical severity, with an adjusted R^2 greater than 0.80 in simulations, confirms its consistency.

The psychometric validation design proposed in the literature considers the reflective dimension through confirm-atory factor analysis (CFA) and the formative dimension through predictive correlation analysis, in line with cur-rent methodological demands for scale analysis in veterinary medicine (16). using SPSS software.

Results

The univariate distribution histograms for each variable (Figure 1) are located on the main diagonal. Humidity shows an approximately normal distribution with positive skewness and a predominance of values between 50% and 80%, which is typical of the Andes. Animal density concentration fell

within the range of 10–20 guinea pigs/m², indicating a relatively homogeneous production management system. The temperature distribution was between 15°C and 28°C, with an average of around 22°C, characteristic of the warmer microclimates found in the temperate Sierra. Figure 1 represents the distribution and bivariate relationship between three environmental predictors: relative humidity (%), animal density (guinea pigs/m²) and ambient temperature (°C), derived from field records in the 50 farms sampled across the ten provinces of the Ecuadorian Sierra.

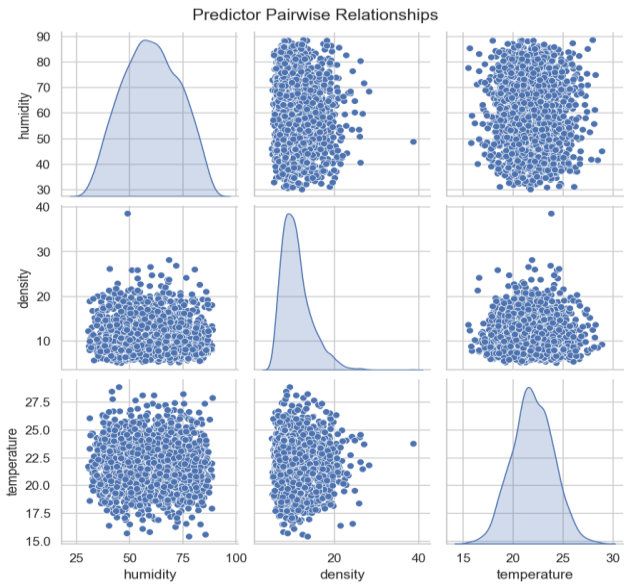

Figure 1: Paired relationships between environmental predictors in guinea pig farms in the Ecuadorian Sierra. (801x768bp).

The off-diagonal scatter plots showed little linear correlation between the variables, indicating relative independence among humidity, temperature, and density. In the humidity–density panel, the points were clustered vertically, Likewise, the –humidity and temperature–density diagrams showed diffuse point clouds and unpatterned systems. The frequency of observations of 0 and 1 is very high. Regulation 780. Clinically healthy animals with mildly mod-erate respiratory signs, grade 0; and with 2 per 450, as opposed to grade 3+, which constituted less than 10% of the total (Figure 2).

The frequency with which different respiratory clinical severity classes were identified in guinea pigs (Cavia por-cellus) in the Ecuadorian highlands, using the GPRCSS (Guinea Pig Respiratory Clinical Severity Scale), is presented in Figure 2. The histogram presents the results in four severity levels from 0 to 3, with 0 indicating the absence of respiratory disease and 3 being the most severe, with dyspnea, cough, and lethargy.

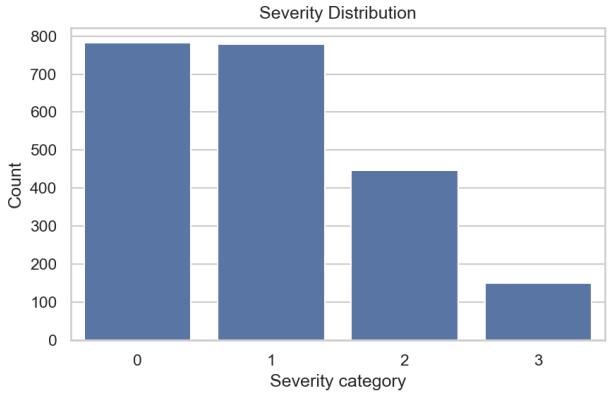

Figure 2: Distribution of clinical respiratory severity in guinea pigs in the Ecuadorian Sierra (591x886 bp).

Figure 3 shows the correlation heat map of the 50 guinea pig farms in the Ecuadorian highlands. The matrix shows the Pearson correlation coefficients between the environmental variables of relative humidity, guinea pigs per square meter, temperature and ventilation, and the dependent variable, the severity of the respiratory crisis, which is measured on the GPRCSS scale.

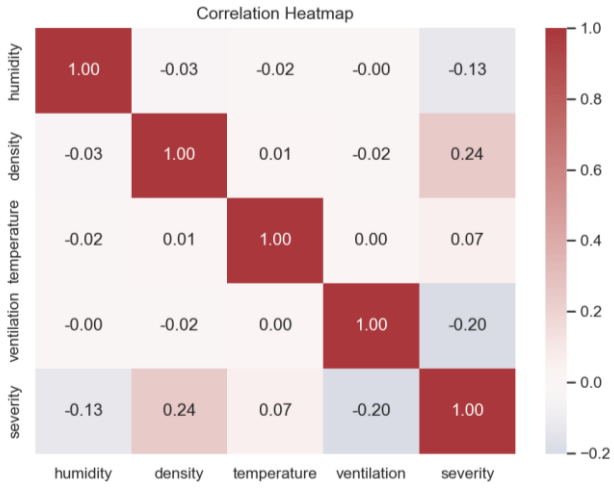

Figure 3: Map of correlations between environmental variables and clinical respiratory severity in guinea pigs (530x689 bp).

Most correlations were low or moderate, suggesting relative independence for most environmental indicators. How-ever, trends consistent with physiology and the production context can be highlighted. A moderate positive correlation (r = 0.24) was identified for respiratory crisis severity, as guinea pigs per square meter were frequently observed with respiratory crisis.

The heat map in Figure 4 illustrated weekly changes in the severity of respiratory distress in laboratory guinea pigs. These animals were monitored over a 12-week period on 50 farms located in the highlands of Ecuador. Light colors on the map indicated that a high proportion of the population fell into a specific severity category, while darker colors indicated that a smaller proportion of the population fell into that category, according to the intensity scale on the right.

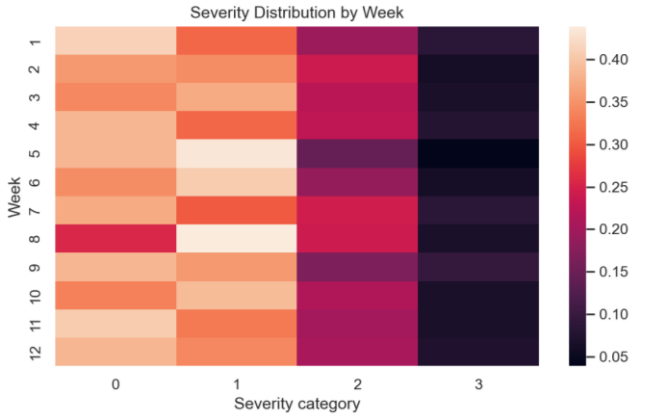

Figure 4: Temporal distribution of respiratory clinical severity in guinea pigs during 12 weeks of monitoring (385x598 bp).

Figure 5 presented a stacked bar chart analyzing the proportion of each respiratory clinical severity category (0–3) as a function of the ventilation level categories on the farms assessed. The following table compares conditions of low or inactive ventilation (0) and high or active ventilation (1).

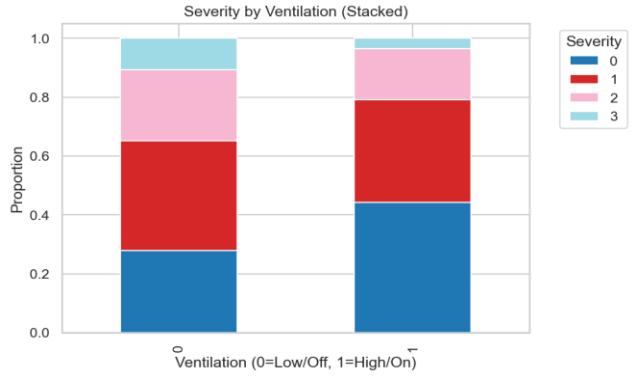

Figure 5: Proportion of clinical severity categories according to the level of ventilation in guinea pig farms (564x886 bp).

In epidemiological terms, the figure 5 highlighted the value of environmental management in preventing respiratory infections in guinea pigs, suggesting that the introduction of active ventilation systems could significantly reduce the incidence and severe clinical manifestations of these infections in intensive production systems.

Figure 6 presents the estimated coefficients that were obtained from an ordered Probit model along with 95% confidence intervals, illustrating the influence of standardized environmental predictors on clinical respiratory severity in guinea pigs. In this scenario, the model type was appropriate for ordinal dependent variables, which was the case for clinical severity, which ranged from 0 to 3. Such a model allows estimating the probabilities of moving from one severity category to another based on changes in environmental predictors.

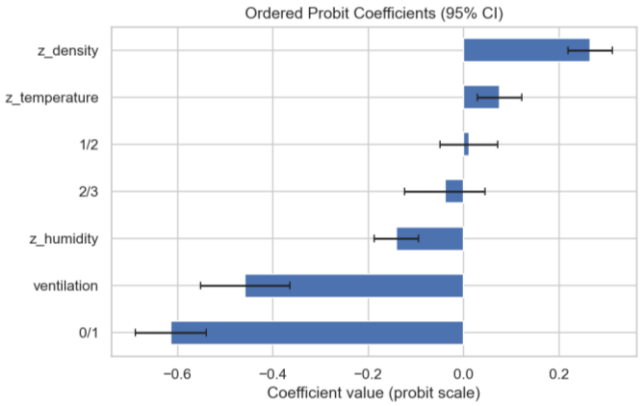

Figure 6: Coefficients of the ordered Probit model for environmental predictors (569x886 bp).

Negative trends in the coefficient of the predictor 'ventilation' (coefficient ≈ –0.45) demonstrated its protective effect against exacerbations of respiratory distress. Similarly, the construct of 'Relative Humidity' (z_humidity) wasshowed a negative coefficient (≈ –0.15), although of a lower magnitude. On the other hand, animal density (z_density) had a positive and statistically significant coefficient (≈ +0.30) and was the predictor with the main influence on the increase in clinical severity.

The points marked "1/2" and "2/3" indicated thresholds in the ordered Probit model that delineate the transition points between consecutive severity categories. Their intermediate position and close separation suggest good calibration of the model to discriminate between mild, moderate, and severe levels.

The estimated probabilities for each severity category of respiratory clinical signs (0-3) in guinea pigs (Cavia porcellus) were attributed to the standardized relative humidity (z_humidity) values of the ordered Probit model, as presented in Figure 7. This particular analysis indicated the change in the severity of clinical signs in relation to changes in ambient humidity, providing information on the severity of respiratory tract irritation.

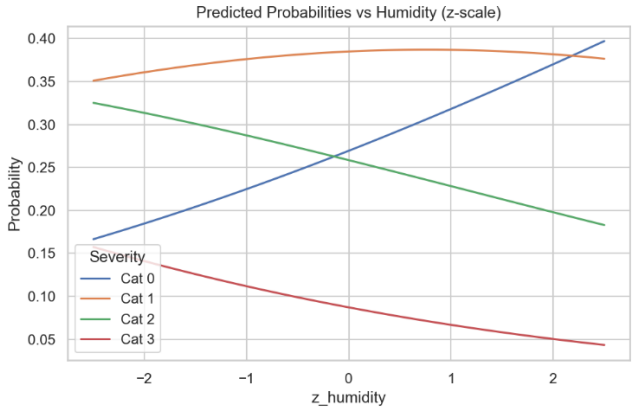

Figure 7: Predicted probabilities of clinical severity as a function of ambient humidity (standardized scale) (569x886 bp).

Figure 8 illustrated the predicted probabilities for each clinical respiratory severity category 0–3, according to the z_density of *Cavia porcellus*, derived from the Probit model fitted to the study's observational data. The influence of animal density, expressed as guinea pigs per square meter, on the manifestation of different levels of respiratory distress was more clearly understood through the predicted probability of respiratory distress.

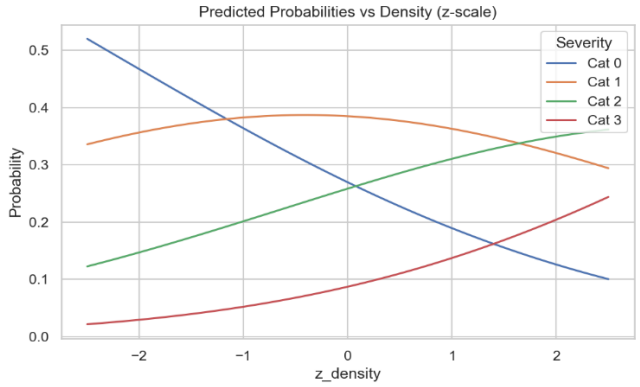

Figure 8: Predicted probabilities of clinical severity according to animal density (standardized scale) (509x791 bp).

As the density of clinical respiratory cases increases, the probability of having mild cases also decreases. The most severe category of respiratory cases increases from 0 (no respiratory distress) to 1 (very mild respiratory distress), while cases of moderate distress, corresponding to categories 2-3, increase, indicating increasing severity.

At very low densities (z < -1), category 0 reaches probabilities greater than 50%, as more than half of the total ani-mals maintain normal respiratory condition. However, at higher density values (z > +1), the probability of category 0 decreased to less than 15%, and, in contrast, the probabilities of categories 2 and 3 increased steadily and together exceed 40%.

Discussion

This initial exploratory analysis suggested that specific environmental conditions were heterogeneous across farms, but not collinear. This suggests that their simultaneous inclusion in the Bayesian hierarchical model was appropriate for the purpose of estimating the incidence and severity of respiratory infections, without the risk of multiplying collinearity.

The decrease in the proportion of guinea pigs with severe manifestations by week 12, as observed in the thermal pattern of the map, may indicate underlying control of environmental exposure or an adaptive immune response of the animals to an initial outbreak. This behavior suggests a distribution curve skewed toward lesser severity, which is consistent with produc-tion systems characterized by predominantly acceptable environmental conditions and a moderate incidence of respiratory infections.

As humidity increases, the probability of clinical cases in the most severe categories (2 and 3) decreases markedly. Conversely, the probabilities for the lowest categories, 0 (no clinical signs) and 1 (mild), also increase. This demonstrated that animals exposed to low humidity levels (z < -1) were more likely to exhibit signs of respiratory stress in the moderate to severe range, confirming that low humidity levels can increase respiratory tract irritation and promote bacterial proliferation.

The probability of showing clinical signs of disease in the lower severity categories (0 and 1) becomes predominant as humidity approaches and exceeds the average (z ≥ 0), with these categories collectively exceeding 70% of the predicted observations. The gently curvilinear shape of the lines indicated that the effect of humidity was not linear, but rather presents an inflection point around the ambient average (z = 0), after which the benefits of humidity in reducing severity tend to stabilize. This was justified the use of nonlinear terms (e.g., polynomial or spline) in the hierarchical Bayesian models that were subsequently used.

The results were showed that ventilation, in this case, affected the clinical severity inversely. In farms with ventilation level 0, the proportion of animals with respiratory signs in categories 2 and 3, moderate and severe, was visibly high, re-flecting an environment that favors the accumulation of irritating gases and a humid environment, as well as a high aerosol particle load. In contrast, farms with ventilation level 1 had a considerable percentage of animals in categories 0 (no signs) and 1 (mild), signs that suggest the existence of a space where pathogen load conditions and animal welfare are positive.

Ventilation decreases the severity (r = -0.20) of symptoms due to the scarcity of pathogenic crises, suggesting that spaces with air in crisis may contain pathogens. Relative humidity also had a very weak negative correlation with severity (r = -0.13), reflecting the intricate relationship between humidity and microbial viability described in air-borne transmission studies. There was no significant correlation between temperature and severity (r = 0.07), sug-gesting that thermal variations within the observed range (15–28°C) do not directly impact the severity of respira-tory distress episodes. The weak correlations among all predictor variables (all $|r| < 0.3$) suggest a lack of signifi-cant multicollinearity and, therefore, the simultaneous inclusion of these predictors in the hierarchical Bayesian model. This finding supports the imported conditions for the space-time analysis of the incidence and severity of respiratory infections.

In weeks 1 to 4, the dominance of category 0–1 indicated that most animals were asymptomatic or showed only mild clinical signs. This result is was consistent with the initial phase of environmental health and stability. From week 5 onward, there was a slight increase in the proportion of animals in severity categories 2 (moderate) and 3 (severe).

Weeks 7 and 8 show clear fluctuations with a slight increase in severity level 2, followed by a progressive decline, reflecting the typical dynamics of self-limiting outbreaks in confined populations. This temporal pattern reinforces the hypothesis that weekly variability in clinical severity is primarily due to microenvironmental factors (ventila-tion, humidity, and density) rather than persistent underlying pathogenic causes. Consequently, longitudinal mon-itoring of these variables allows for the identification of risk patterns and the implementation of changes in man-agement practices to reduce the incidence of respiratory cases in high-altitude agriculture.

Overall, the analyses were confirmed that adequate ventilation significantly decreased the likelihood of severe cases, while high density and temperatures contributed to clinical worsening. These findings support the proposed hierarchical Bayesian approach, in which the interaction of these factors will be jointly modeled to estimate the incidence and severity of respiratory conditions on farms across the Ecuadorian Sierra.

The curve corresponding to category 1 (mild) had a parabolic shape and reached a maximum at $z \approx 0$, which can be interpreted as indicating that mild cases are more frequent at intermediate densities, that is, before overcrowding reaches the most intense clinical phase. This nonlinear behavior of the curve was precisely what indicated the need to incorporate higher-order effects, whether quadratic or spline.

Estimation of the incidence and severity of respiratory clinical illness in 50 guinea pig farms in the Ecuadorian highlands using a Bayesian random-effects model with informative priors and validation using the WAIC criterion and subsequent predictive check (PPC). An increase in severity was recorded in the middle of the series with a subsequent return to a stable phase.

The research supports the hypothesis that: (i) ventilation is related to a reduction in clinical severity; (ii) clinical severity is related to density (or strain combination); and (iii) clinical severity decreases with moderate relative humidity. Regarding the respiratory pathophysiology of guinea pigs and the airborne pathophysiology of disease transmission to guinea pigs, ventilation decreases the concentration of irritating particles and gases, and moderate humidity decreases mucosal irritation and helps with the deposition of infected aerosols. This has been documented in rodents and vivariums, where ventilation cycles, NH_3/CO_2, and mucosal dysfunction influence pathogen load, and ventilation cycles influence dysfunctional mucosa (4,5,17). Respiratory dysfunction and the transient portion of the intermediate peaks suggest the circulation of a single, highly virulent pathogen, sustained by self-limiting outbreaks and/or corrections in environmental management.

The results obtained are consistent with documented observations linking microenvironment and respiratory health in rodent models, given that increases in NH_3, resulting from overcrowding and poor ventilation, have been suggested to increase risk. In fact, active ventilation and air management have been documented to reduce risk exposure. Contagion due to humidity and its magnification effect are related to physical and experimental aerosol models and to evidence of respiratory viruses in animal models. There are differences with reports mentioning se-vere clinical reactions in experimental studies of asthma or allergy (18,19).

These differences can be explained by challenge with specific allergens at high levels and under controlled conditions versus our field environment with various agents and exposures at intermediate levels. Attention to well-being and its management (20-24), also helps to understand why in systems with best practices, severity is lower. The introduction of a specific clinical instrument (GPRCSS) and multicenter documents quantifying ventilation-density-humidity in relation to severity in production guinea pigs, which has been documented less than in laboratory or pet guinea pigs. Second, we demonstrated the applicability of the Bayesian GLMM with PPC and WAIC for the assessment of ordinal severity and nonlinear effects (humidity) in the spatiotemporal plane, linking the modeling literature with veterinary practice and its field. Third, our results are integrated with the literature on reservoirs and coinfections in Andean guinea pigs (14,25-27), with the environmental layer quantified as an additional contribution. The observed pattern was consistent with a mixed causal model, where population density exerts pressure that elevates microbial load and triggers NH_3/CO_2 accumulation,

ventilation mitigates this pressure, and humidity acts as a nonlinear modulator of aerosol transport and viability. This framework is in dialogue with recent literature on disease transmission and the environment–host–agent triad (28-30).

Despite the relevance of the results, the observational design—the Bayesian GLMM is designed to handle confounding and the hierarchical structure of the design—does not offer a strict causality test. Limited etiological focus: We prioritized *Bordetella* due to its relevance; other etiologies (*influenza* A, *Leptospira*, protozoa) that can modify clinical manifestations have been reported in the region (25-27). Clinical scale: The GPRCSS was internally validated but will require cross-validation and invariance analysis for transferability to other contexts, similar to recommendations for education/simulators and pharmacology scales (31). Host processes and micro-biome-lung interactions were not explicitly modeled (32). Although temperature was considered, light-rhythm interactions, oxidative stress, and other environmental factors such as PFOA were not assessed and could act as modifiers. Some clinical outcomes could have been influenced by adjuvant therapies on farms; the pharmacological literature on guinea pigs suggests bronchial responses to drugs (33), which we did not control for. Based on these findings, Bayesian spatiotemporal modeling (BYM2/RW2) with nonlinear effects, splines for humidity and temperature, and more comprehensive fitting comparisons in WAIC/DIC and PPC are proposed for future research. Quasi-experimental studies are proposed to evaluate ventilation and density interventions with continuous monitoring of NH_3/CO_2 and bioaerosols, and monitoring of environmental control protocols (17). Expanded etiological surveillance is proposed: use of multiplex panels for bacteria/viruses/fungi; regional results should be considered in the integration (14,25-27). Likewise, it is recommended to evaluate the effects of management and diet on mucosal immunity and respiratory symptoms, in interaction with nutrition, probiotics, and net energy (34-37), welfare and behavior: housing tests and COM-B, and their relationship with respiratory indicators (20-22) and immunoprophylaxis and treatments: evaluation of vaccines (38-40) and bronchodilator agents as supportive measures (33).

The use of statistical methods should also be considered: exploring alternative distributions for heavy tails or non-proportional ordinal arrangements (41) and comparative analysis using a frequentist approach; incorporating half-life and survival analysis if extended to mortality (42), for the assessment of occupational risk and biosafety by quantifying the correlation between mask/respirator handling (30) and laboratory animal allergy (43) with environmental and clinical indicators. Despite being peripheral to the respiratory focus, several works illustrate the breadth of the guinea pig as a model and provide useful frameworks: cardiovascular/neurobiological and otological physiology (44,45), developmental biology and the biology of aging (42,46), T cell immunology (47), and vaccine safety (48). These bodies of evidence underline the transferability of measurement methodologies, bias control, and statistical analysis to respiratory studies in the field of animal production. Furthermore, the literature on productivity and livestock breeding systems (34,35,49) provides management contexts that indirectly influence ani-mal density and welfare, key elements of these models.

This finding aligns with previous research conducted in confined microenvironments, where overcrowding facilitates the accumulation of harmful gases, such as ammonia and carbon dioxide, and increases the concentration of aerosolized pathogens. From a pathophysiological perspective, sustained exposure to these compounds causes mucosal irritation, oxidative stress, and decreased ciliary function, which promotes bacterial colonization. Thus, stocking density, the reported condition, emerges as a productive indicator, but also as a health determinant that should be incorporated into regulatory frameworks based on animal welfare, and adapted technical management should be integrated as an adjustment to the high-altitude production system.

Adequate ventilation leads to a considerable reduction in the incidence and severity of respiratory disease. In contrast, farms with poor ventilation had a higher prevalence of animals with moderate to severe clinical respiratory signs, while farms with active airflow had a higher proportion of animals with mild or asymptomatic disease. This inverse relationship, confirmed by both the Pearson correlation and the negative coefficients of the ordered Probit model, reinforces the hypothesis that air quality is a crucial modulator of respiratory balance in guinea pigs. Continuous ventilation, as described, improves oxygenation, reduces excessive humidity, and prevents the accumulation of irritating gases. These conditions, together, reduce pathogen load and promote immunological homeostasis. Therefore, forced and passive ventilation should be considered priority health measures.

Conclusion

The research demonstrated that, at moderate levels (50–80%), environmental humidity acts as a protective factor. The results obtained using Bayesian models, as well as predicted probability curves, show that, at the extreme, very low humidity is associated with an increased risk of developing acute respiratory illnesses, as it causes mucosal desiccation and decreases the effectiveness of mucociliary clearance. In contrast, intermediate humidity levels favor the preservation of epithelial integrity and decrease the viability of aerosol-transmitted microorganisms. This nonlinear effect suggests the existence of a physiological threshold of

optimal humidity, above which the benefit stabilizes or is lost.

The findings suggest that for Andean farms, we suggest: (i) continuous active ventilation (which is timely in the event of HVAC outages;; (ii) maintaining target densities that minimize NH_3 (in line with the systemic effects of ammonia, especially in neonatal pigs;; (iii) maintaining intermediate humidity; (iv) incorporating environ-mental monitoring and standard weights into body condition assessment; (v) evaluating (under a cost-benefit analysis) immunoprophylactic interventions (BCG and respiratory in guinea pigs;. Environmental management is equated with welfare guidelines and the reduction of occupational allergies. This contradicts data demonstrating that overcrowding and housing conditions impact health.

The most prominent predictor of the clinical severity of respiratory distress in guinea pigs is guinea pig population density. The population density, in guinea pigs, is considered the most prominent predictor for the clinical severity of respiratory distress in these animals as the animal population per square meter increases, the likelihood of observing signs of moderate and severe respiratory distress increases. The main element that affects the seriousness of breathing problems in guinea pigs is the size of their groups. Studies show that when these animals live in larger numbers, there is a notable rise in cases of breathing difficulties. This connection implies that the more guinea pigs present in a particular area, the greater the chance of encountering significant respiratory distress. Elements like poor air circulation, elevated stress, and a higher spread of diseases in crowded conditions play a role in this situation. Therefore, it is vital to recognize and regulate population size to ensure the health and welfare of guinea pigs, especially in places like breeding centers or laboratories where they are often housed closely together.

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Conflict of interest

There is no conflict of interest.

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النمذجة الهرمية البايزية لالتهابات الجهاز التنفسي لدى خنازير غينيا

كريستيان إنكا[1]، فرانكلين كورونيل[1]، إم إرمنيكا ألكسندرا كاستيلو رينا[1]، لويس أرماندو كويشبي هيبو[1]، إيفلين إنكا[2]

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الخلاصة

تعتبر المكورات العنقودية الذهبية هي العامل المسبب الرئيسي لالتهاب الضرع البقري في جميع أنحاء العالم. بالإضافة إلى ذلك، فان تُمثل التهابات الجهاز التنفسي لدى خنازير غينيا (*Cavia porcellus*)، وهي نوع ذو قيمة تجريبية وإنتاجية عالية في منطقة الأنديز، تحديًا صحيًا متكررًا في مرتفعات الإكوادور .ونظرًا لحساسيتها للتغيرات البيئية الدقيقة، هدفت هذه الدراسة إلى تحديد العوامل البيئية والسريرية المرتبطة

بشدة أمراض الجهاز التنفسي .جُمعت البيانات من ٥٠ مزرعة، بما في ذلك متغيرات مثل الرطوبة النسبية والتهوية ودرجة الحرارة والكثافة السكانية، إلى جانب المؤشرات السريرية للسعال وضيق التنفس وسيلان الأنف والخمول .حُللت المعلومات باستخدام نموذج مكاني زماني بايزي هرمي، مما سمح بدمج المحددات البيئية والفسيولوجية والسببية ضمن إطار استدلالي متين .أظهرت النتائج أن الكثافة السكانية كانت عامل الخطر الرئيسي، مما أظهر ارتباطًا إيجابيًا بالشدة السريرية .في المقابل، أدت التهوية الكافية والرطوبة المعتدلة إلى تقليل وتيرة الأعراض التنفسية بشكل ملحوظ .أدى ضعف تبادل الهواء إلى تراكم الغازات المهيجة مثل الأمونيا وثاني أكسيد الكربون، مما ساهم في انتشار بكتيريا البورديتيلا برونشيسبتيكا. تجاوز النهج البايزي قيود الطرق التكرارية التقليدية من خلال توفير تقديرات أكثر دقة لشدة المرض من خلال مقياس الشدة السريرية للجهاز التنفسي لخنزير غينيا .وفي الختام، أثبت النموذج البايزي الهرمي فعاليته كأداة تنبؤية لإدارة مستدامة للصحة التنفسية في أنظمة إنتاج خنازير غينيا في المرتفعات، مما ساهم في رعاية الحيوان وتحسين ممارسات الإدارة البيئية.