

Assessing the Resilience Factor: A Preliminary Investigation into a Multifaceted Approach to Individual Parasite Control in Thoroughbred Foals

Eduarda Proença¹, Irineu R. Neto¹, Alan J. Ferreira², Ursula Y. Yoshitani¹, and Marcelo B. Molento^{1,*}

¹Laboratory of Veterinary Clinical Parasitology, Federal University of Paraná, Paraná, 80.035-050, Brazil

²Haras Rio Iguassu, Avenida Victor Ferreira do Amaral, Paraná, 82.800-000, Brazil

* Author to whom any correspondence should be addressed; Email: molento@ufpr.br

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Abstract

Standard equine management practices contribute to the high prevalence of strongyles and to the need for deworming. Horse performance can be evaluated by following early body development. This study aimed to determine the behavior and body growth associated with strongyle fecal egg count (FEC) in 25 Thoroughbred foals aged from birth to 10 months in southern Brazil. Body weight, withers height, and FEC were determined monthly, and foals' behavior/personality was recorded twice daily by resident veterinarians following standard welfare protocols. A generalized linear mixed model was used to analyze body growth and FEC variance. There was a high correlation between weight gain before six months of age and between height and age. Although males exhibited greater variability in weight and height, no statistically significant differences were observed between sexes ($P > 0.05$). There was no significant association between strongyle FEC and body weight or height in any animals. Descriptive behavioral analysis revealed that only four animals were treated based on behavior/personality alterations and clinical signs (i.e., abdominal discomfort). The data showed a null-to-weak correlation between FEC and the animals' age ($R^2 = -0.025$ for females and $R^2 = 0.168$ for males). Moreover, foals had a low (0.206) FEC repeatability coefficient for sex and age, while individual overdispersion indicated a high (3.919) value. This information is crucial when designing health protocols for horses, as the expected rise in FEC after treatment may indicate a new infection that accompanies a suppressive drug strategy. These preliminary data showed that foals experienced steady body growth, independent of FEC, allowing selective treatment to be guided by a combination of periodic clinical and analytical parasitological examinations. Furthermore, this study highlights the intrinsic influence of constant veterinary care and the protection of horse health as a strong component of farm resilience.

Keywords

Strongyle; body growth; yearlings; gastrointestinal infection; personality

1. Introduction

Standard management practices in horse breeding contribute to a high prevalence of parasitic infections during the first weeks of life. Helminth parasitism poses a significant challenge to equine health, as several species frequently

infect horses at this stage [1]. Among them, cyathostomins are the predominant helminths in Brazil [2]. High infection levels may cause clinical complications such as anemia, diarrhea, weight loss, peripheral edema, and even death [3]. These effects can compromise weight gain, as thousands of

encysted larvae may cover the intestinal mucosa, impairing nutrient absorption [4].

The development of parasitic disease depends on both exposure intensity and the host's immune and physiological responses. Genetic background, nutritional deficiencies, and chronic stress can increase susceptibility, leading to variability in individual responses to nematode infection [5]. The fecal egg count (FEC) test remains a valuable tool for monitoring egg shedding, selecting animals for treatment, and reducing pasture contamination [6]. FEC-based selective treatments also limit anthelmintic use and reduce selection pressure for resistance, as the parasite population in untreated animals remains unexposed to the drugs [7].

Animal welfare assessment in horses involves interactions among behavioral responses, stereotypies, and physiological indicators [8]. Parameters related to nutrition, health, behavior, and pain have been used as welfare indicators in naturally infected horses in southern Brazil. No significant relationship was observed between FEC and these indicators, suggesting that FEC alone is not a reliable measure of welfare when animals are maintained under adequate nutritional and health conditions [2].

Moreover, body size is primarily determined by genetics, and measurements taken during the early months of life reflect both genetic potential and expected adult size [9]. Nevertheless, environmental conditions, nutritional status, and sanitary management also influence growth rate. Studies have shown that suckling foal growth varies by birth month and season [10] and that between weaning and one year of age, seasonal factors consistently affect growth [11]. Body weight and withers height are central indicators of performance, and long-term monitoring of large foal populations has supported predictive models for the development of Thoroughbred foals in Brazil [12].

In most horse farms in Brazil, parasite control relies on the routine use of broad-spectrum anthelmintics due to their efficacy and safety. However, over the last two decades, widespread anthelmintic resistance in cyathostomins has been increasingly reported [13], including evidence from fecal egg count reduction tests (FECRT) indicating resistance to macrocyclic lactones [14–16]. In this context, selective therapy based on FEC monitoring has been proposed to manage parasitic infections while minimizing the development of drug resistance [17]. Clinical evaluation of body condition, weight gain, and withers height can complement FEC results to guide treatment decisions [18].

Thoroughbred breeders aim to prepare young horses for training and competition from approximately 30 months of age [10]. Economic assessments have demonstrated the feasibility of FEC-based targeted selective treatments [19]. Furthermore, bioeconomic analyses conducted under tropical conditions have revealed that treating only animals with the highest FEC values can reduce drug use without increasing the overall costs [20]. More recently, a 10-year field study

in Sweden demonstrated the practicality of such FEC-based control schemes, reinforcing their value for sustainable parasite management [17].

The literature integrating behavioral characteristics, clinical signs, body growth, and FEC to identify resilient foals under natural grazing conditions is currently limited. Additional physiological measurements (i.e., cortisol and hemogram) are still based on standard literature [8]. Therefore, the objective of this study was to determine whether FEC influences growth performance and behavior in naturally infected Thoroughbred foals, using an analytical decision-making protocol. This holistic methodology aligns with contemporary movements in veterinary parasitology, particularly in light of drug resistance and animal welfare [21].

2. Materials and Methods

2.1. Animal Management and Health Protocol

The study enrolled 25 newborn Thoroughbred foals from one farm in Tijucas do Sul, southern Brazil, born between July and December 2022. The animals were followed from January to October 2023. The area had native pasture in summer and *Lolium multiflorum* (ryegrass) in winter. Four regular pasture areas were used to accommodate 7 to 8 animals (animal density = 0.78), based on pasture quality and suitability, with no rotation or other grazing management practices. Animal distribution was considered by birth order, ensuring that males and females of similar ages were equally represented in each paddock to minimize animal and environmental bias. The animals were taken to the main stable twice daily to receive alfalfa (*Medicago sativa*) and 1.5 kg of a 16% protein mix. Individual pasture intake during free-grazing periods was not quantified.

The health protocol included monthly assessments of growth rate and weight gain. Foals' behavior was monitored daily using a standardized welfare protocol (Table 1) [2]. All observations were conducted by a trained resident veterinarian team as part of routine clinical management, allowing early identification of clinical or behavioral deviations potentially associated with parasitic infections. Behavioral sampling began with a 15-minute acclimation period and was conducted daily at 08:00 a.m. and 04:00 p.m. in the paddocks. Scan sampling was performed according to Table 1, starting approximately 5 meters from the foals and gradually approaching 2–3 meters for the human–animal approach test. During each session, behavioral indicators, including alertness, posture, responsiveness to the evaluator, avoidance, apathy, and uncommon events such as sweating, were documented in real time and summarized into frequency distributions to detect patterns or deviations indicative of welfare impairment. This integrated health and behavioral monitoring was used to support clinical decision-making, particularly regarding the need for antiparasitic treatment. Body condition score (BCS) was also evaluated monthly on a scale of 1 (emaciated) to 9 (heavily obese). Mares were not dewormed during gestation.

Table 1: Health and behavior parameters that were evaluated in the welfare protocol applied to 25 Thoroughbred foals from Tijucas do Sul, PR, Brazil.

Category	Behavior	Operational description	Interpretation/ relevance
General state/vigilance	Alert	Head and ears raised; attention to the evaluator	Adequate welfare
	Curiosity	Spontaneous approach toward the evaluator	Positive behavior
	Apathy	Low posture response, reduced movement	Compromised welfare
Posture and locomotion	Voluntary movement toward the gate	Coordinated movement during feeding times	Anticipatory behavior
	Immobility/Abnormal movement	Lack of movement when approached by a caretaker	Possible intestinal stress
Human interaction	Response test (2–3 m)	Slow movement toward or away from the evaluator	Tolerance, interest, or avoidance of humans
	Interest/approach	Voluntary approach toward the evaluator	Positive welfare
	Avoidance	Moving away from humans	Signs of discomfort
Social interaction	Group play	Jumping, mutual touching, playful behavior	Common in foals, an indicator of vitality
	Synchronized running	Group movement in the same direction	Social behavior of foals
	Proximity to conspecifics	Remaining close to others, especially near fences	Normal social sign
	Social withdrawal	Foal remaining away from the group	Sign of possible discomfort or illness
Reactivity/handling	Responsiveness to touch	Remaining calm when touched by the evaluator	Behavior based on the AWIN protocol
	Avoidance in handling	Stepping back, escape from touch	Normal in foal development
Indicators of discomfort or pain	Lowered ears	Ears held backward for a period of time	Nonspecific sign of discomfort or pain
	Unusual sweating	Localized sweating outside exercise	A marker of stress, pain, or an uncommon event
	Reduced voluntary movement	Lack of response to stimuli, failure to move	Possible intestinal discomfort
Environmental exploration	Sniffing objects/people	Exploration of veterinarians, caretakers, or environmental elements	Healthy behavior

2.2. Evaluation of Body Development and Coproparasitological Testing

All animals were checked monthly using a scale (Lider, Araçatuba, Brazil) and a hippometer (WalMur, Montevideo, Uruguay) to monitor weight (kg) and height (cm), respectively [22]. Individual fecal samples were collected from the rectum of the animals and transported to the laboratory in styrofoam boxes for processing within 24 h. Individual coproparasitological examinations were performed using the modified Gordon & Whitlock [23] technique with a conversion factor of 25 [24]. Subsequently, a pooled fecal sample was used to harvest and identify third-stage infective larvae (L3). All analyses were performed in triplicate, with 50 larvae analyzed per repetition [25].

2.3. Climate Data

The National Institute of Meteorology (INMET, Brazil) provided the monthly climate data, including average temperature (°C) and precipitation (mm³), for the Tijucas do Sul region. The meteorological data were obtained from the CURITIBA-A807 weather station, located in Curitiba, PR, Brazil.

2.4. Statistical Analysis

The power of the test was adjusted to 35 births on one farm, as horse management adopted a behavior-based protocol. Therefore, the sample size ($n = 25$) was determined based on a 90% confidence level, with a 10% margin of error. The value of n was obtained from the finite population equation (1) represented below, with z defined as 1.645 for 90% confidence, p conservatively defined as 0.50 in the absence of previous

prevalence data, $e = 0.10$ as the absolute precision, and $N = 35$ representing the number of eligible births on the farm; the denominator term applies the finite population correction.

$$\text{Sample Size} = \frac{\frac{z^2 \times p(1-p)}{e^2}}{1 + \frac{(z^2 \times p(1-p))}{e^2 N}} \quad (1)$$

The weight and height data of the animals were adjusted using the Generalized Linear Model (Proc-GLM) for a Normal (Gaussian) distribution. The nonparametric Spearman test was used to assess the correlation between weight and height by age and by age and sex. The nonparametric Wilcoxon rank-sum test was used to compare males and females within each age group. Nonparametric tests were selected for correlation and group comparisons because preliminary diagnostic checks indicated that the weight and height data did not meet the assumptions of normality and homoscedasticity required by parametric methods. Since Spearman's rank correlation and the Wilcoxon rank-sum test do not assume normality, linearity, or normally distributed residuals, a log transformation was not applied. Linearity was evaluated only for the components analyzed using the Generalized Linear Model (Proc-GLM), for which residual diagnostic plots (residuals vs. fitted values and Q-Q plots) were examined to verify model adequacy. Spearman's correlation was used to assess monotonic associations rather than linear relationships, which eliminates the need to test for linearity. Statistical significance was set at a 5% level ($P < 0.05$). The median test was used to assess whether there was a statistically significant difference in median weight between the sexes.

For FEC data, three models were adjusted using the Zero-Inflated Negative Binomial Regression Model methodology. FEC variability was partitioned among repeated measures for each individual, with the animal identifier (Animal ID) included as a random effect in the generalized linear mixed model (GLMM). This structure allowed the authors to account for temporal dependence among observations and to separately estimate the variance attributed to individual differences (between animals) and residual variance (within animals over time).

The repeatability analysis of fecal egg counts (FEC) was performed using a generalized linear mixed model (GLMM) with a Poisson error distribution and an overdispersion term, adopting a link-scale (latent-scale) approximation to decompose variance components. The 95% confidence intervals, standard errors, and repeatability estimates were obtained via parametric bootstrapping with 500 iterations. In contrast, the statistical significance of the variance components and repeatability coefficients was assessed using

the Likelihood Ratio Test (LRT). The association between treatment status and egg shedding was assessed using odds ratio analysis with a 95% confidence interval. A descriptive analysis was employed to examine welfare, monitor subtle changes in horse behavior, and detect uncommon events. The tested hypothesis evaluated whether the variances and repeatability coefficients for the animal groups and the overdispersion differed from zero. All statistical analyses were performed using R, version 4.4.0 (i386).

3. Results

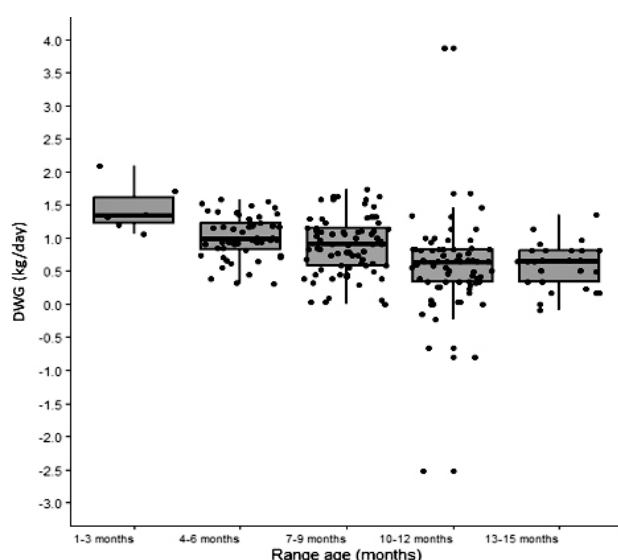
According to the behavior assessment (Table 2), foals displayed alertness, curiosity, and anticipatory behavior in 99.2% of observations, while positive human-directed exploratory behaviors were recorded in 82.0%. Social behaviors such as group play and proximity to conspecifics were frequently observed. In contrast, deviations indicative of potential welfare compromise occurred only 3.6% of the time, and behavioral changes directly associated with parasitic infection were identified in just four foals throughout the study period. Throughout all evaluations, the foals had BCS within the 4–6 range, considered appropriate for young animals, with overall stability across monthly measurements. Only two individuals were classified as underweight (BCS 3), slightly below the expected condition, during a single assessment, with no recurrence in subsequent weightings. No overweight animals were observed (data not shown).

Coprological analysis revealed a predominance (79.9%) of the *Strongylidae* superfamily, followed by *Parascaris spp.* (19.9%). Coproculture enabled the identification of L3 from various cyathostomin groups (A, B, C, D, and F), as well as *Posteriostrongylus* spp. and large strongyles, including *Triodontophorus* spp. and *Strongylus vulgaris*. Among the identified cyathostomins, type A (63%) and C (19.5%) were the most prevalent throughout the study. Considerable variation in parasite egg shedding was observed among individuals, with standard deviations of approximately 728 EPG for females and 628 EPG for males. The data reinforce the heterogeneous distribution of parasites in horses. Climate data also revealed a weak negative correlation between FEC and temperature ($r = -0.1482$). In contrast, a moderate positive correlation was observed between FEC and precipitation ($r = 0.4973$).

The animals demonstrated continuous body growth, reaching their peak at 15 months of age. It was observed that the average daily weight gain (DWG) varied across age groups. Animals aged 1–3 months showed the highest values (approximately 1.3 kg/day). For animals aged 13–15 months, the DWG dropped to 0.6 kg/day. Regarding variability, the 7–9-month age group showed the most significant variation in DWG (Figure 1).

Table 2: Ethogram-based quantitative summary of behavior of 25 Thoroughbred foals from Tijucas do Sul, PR, Brazil, monitored twice daily over 10 months. Percentage values represent the observations in which each behavior was recorded.

Category	Behavior	Observations	Obs. (%)	Notes/interpretation
General state	Alertness/curiosity	2× day	99.2%	Foals were alert and curious, indicating positive welfare
Posture	Voluntary movement	2× day	99.2%	Good voluntary movement toward the gate at feeding time; good anticipatory behavior
Human interaction	Approaching/exploratory behavior	2× day	82.0%	Positive interest in humans; good habituation to handling and human–animal interaction
Social interaction	Group play	Once daily	~70%*	Positive social/group behaviors, indicative of normal development and adequate welfare
Social interaction	Proximity to conspecifics	Once daily	≥80%*	Maintenance of proximity to other foals; normal affiliation
Deviation from normal	Welfare compromise signs	2× day	3.6%	Sporadic, associated with mild, transient intestinal discomfort during weaning or paddock changes
Associated with parasitism	Behavioral changes associated with parasitic infection	2× day	0.82%	Behavioral/clinical growth alterations linked to parasites

**Figure 1:** Boxplot of the average daily weight gain (DWG; kg/day) at different ages of 25 Thoroughbred foals from Tijucas do Sul, PR, Brazil. Boxes represent the interquartile range, horizontal lines indicate the median, whiskers show data dispersion ($1.5 \times \text{IQR}$), and dots represent outliers.

Greater body weight variability was observed in males than in females (**Figure 2a**). The minimum recorded weight was lower in females (102.0 kg) than in males (131.0 kg), whereas the maximum weight was higher in males (433.0 kg) than in females (422.0 kg). The relationship between body weight and sex was evaluated using the median test, yielding $Z = -1.0863$ and $P = 0.2773$, indicating no statistically significant difference. The minimum height observed was 112 cm for females and 119 cm for males, while the maximum heights were 151 cm and 153 cm, respectively (**Figure 2b**). The median test yielded $Z = -0.6718$ and $P = 0.5018$, indicating no significant difference between sexes.

Figure 3 shows the distribution of FEC across age groups. Animals aged 1–3 months presented the lowest FEC, indicating early infection, compared with the other categories. The highest counts were observed in the 4–6-month-old group. Moreover, two FEC peaks were identified in the 4–6-month age group, with the highest concentration reaching up to 100, while the second peak ranged from 1,400 to 2,200 FEC. Although animals in the 4–6-month age group showed higher FEC, they maintained greater DWG than older animals.

The body growth data did not reveal a significant association between strongyle FEC and body weight ($R^2 = 0.0235$) and height ($R^2 = 0.0209$). The distribution of FEC varied considerably among individuals, with 73.8% of the 183 records falling between 0.0 and 975 (min. = 0.0; max. = 3,750) (**Figure 4**). Only four foals, aged 10–12 months, were treated with a combination of ivermectin 1% and praziquantel 7.5%. The decision was based on clinical signs: liquid feces ($n = 2$), mild abdominal discomfort ($n = 2$), expected weight gain for age ($n = 1$), and the presence of cyathostomins in feces ($n = 2$). FEC was not used as a treatment criterion.

Considering a scenario in which animals are subjected to anthelmintic treatment based on high FEC, an OR analysis was performed to assess the likelihood of an animal being treated (True) or potentially treated based on different ranges. For animals with FEC between 0 and 100, the estimated OR was 0.404 (95% CI: 0.0577–1.4831; $P = 0.1919$), suggesting a likelihood of low FEC among treated animals (False) of approximately 60%. For high FEC values ($\geq 1,000$), the estimated OR was 0.0573 (95% CI). Therefore, the odds of a treated animal being in the high FEC group were only 5.7%.

Additionally, a repeatability analysis revealed consistency of FEC over time ($R^2 = 0.206$), indicating low to moderate within-individual consistency and high individual variability. Contributing to this, the variance associated with overdispersion was substantially high ($VO = 3.919$; $P < 0.001$),

suggesting that most of the observed FEC variability arises from random environmental factors and the aggregated nature of nematode infections, rather than from fixed group or age-level effects.

Two groups of animals were compared based on FEC. Group 1 (FEC 0–100) included 58 observations: 56 from unequivocally untreated animals and two from confirmed or possible

antiparasitic treatment. Group 2 (FEC $\geq 1,000$) included 69 observations: 53 were from untreated animals, and 16 from individuals with confirmed or suspected antiparasitic treatment. The final weights and heights were 300 kg and 142 cm for the low FEC group, and 310 kg and 141 cm for the high FEC group, respectively, showing no statistically significant differences ($P > 0.05$) between the FEC-extreme groups (data not shown).

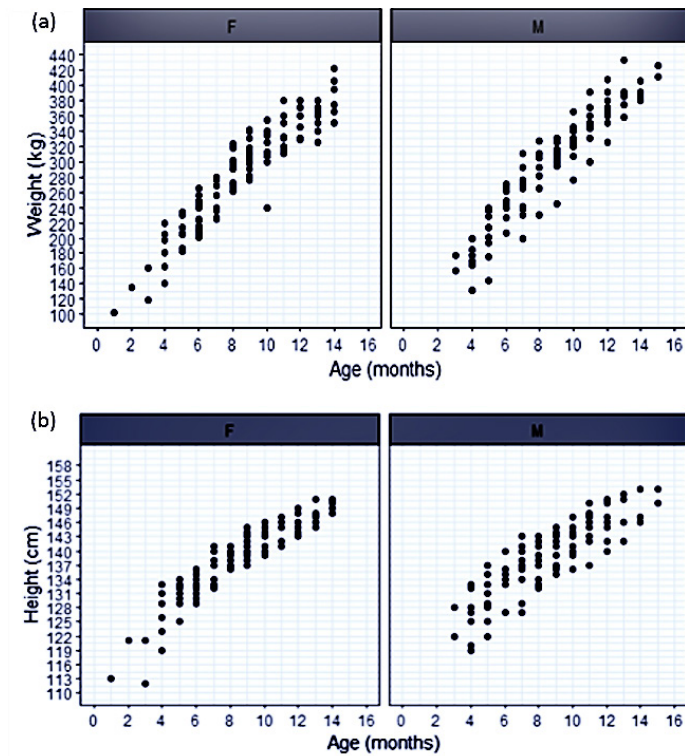


Figure 2: Body growth distribution of male (M) and female (F) Thoroughbred foals ($n = 25$) from Tijucas do Sul, PR, Brazil. (a) Body weight (kg) and (b) withers height (cm) by age (months). Each black dot represents an animal.

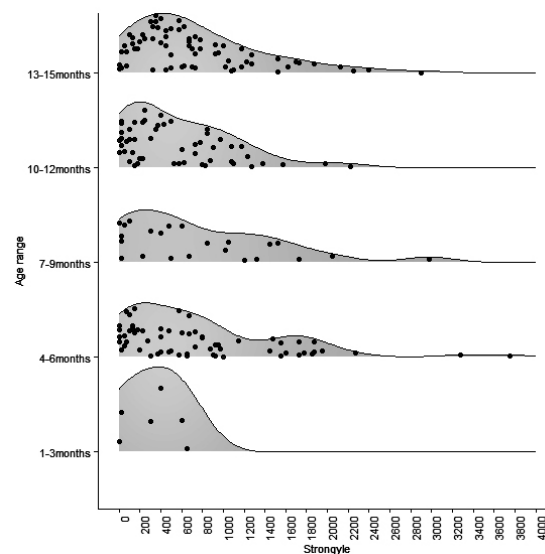


Figure 3: Density distribution of strongyle fecal egg counts of 25 Thoroughbred foals from Tijucas do Sul, PR, Brazil, at different ages. Black dots represent individual data points.

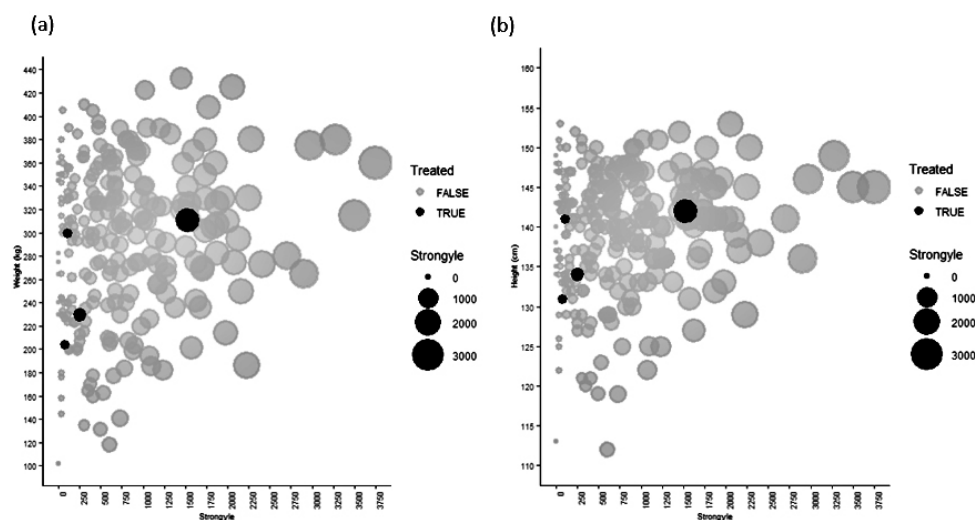


Figure 4: Distribution of strongyle fecal egg counts and (a) body weight (kg) and (b) withers height (cm) of 25 Thoroughbred foals from Tijucas do Sul, PR, Brazil. The size of the circles represents the strongyle egg count; black circles indicate treated animals.

4. Discussion

The behavioral consistency observed throughout the adopted conditions, characterized by high frequencies of alertness, curiosity, anticipatory responses, and positive human-directed interactions, indicates that gastrointestinal parasitism had a limited visible impact on the welfare of the foals. Previous evidence shows that behavioral deviations in naturally infected horses tend to be subtle and often insufficient to reliably differentiate animals with high and low parasite burdens in well-managed systems, which is consistent with the results found here [2]. In the present study, alterations such as apathy, social withdrawal, lowered ear position, and reduced voluntary movement were rare (<4%) and generally associated with transient episodes during weaning or following changes in grazing paddocks, rather than with consistent parasitic loads. The small number of animals showing behavioral changes directly attributable to parasitism (four foals) further supports that low to moderate strongyle exposure tends not to generate robust or observable welfare impairments in young animals.

These results are also consistent with studies demonstrating that indicators such as reduced responsiveness, abnormal posture, avoidance of human contact, and decreased social engagement arise primarily in contexts of significant physiological challenge, including pain or systemic illness, and not merely in cases of mild parasitic infection [26]. The low prevalence and low intensity of behavioral alterations observed in this study support this interpretation. Additionally, there is evidence that parasitic infections may trigger subclinical physiological changes, such as shifts in gut microbiota composition, before overt behavioral changes become detectable, suggesting that behavior may represent a late and relatively insensitive marker of early or acute parasitic stress [27].

The prevalence of *Strongylidae* and *Parascaris spp.* observed in this study follows the epidemiological pattern widely

described in horses. An extensive retrospective analysis conducted in Brazil, involving nearly 20,000 samples over 12 years, reported a prevalence of gastrointestinal helminths of 68.5%. Strongyles were responsible for most infections, and a significantly higher risk was observed in young animals during rainy periods. Mean FEC were 453.5 (± 717.6) for strongyles and 17.1 (± 147.1) for *Parascaris spp.* [13]. Similarly, a study in Thailand reported a 50.9% prevalence of strongylids, with an average of 445.7, and only 25.7% of horses showed values ≥ 200 [28]. Although some selective treatment regimens are based on FEC [17,20], our study did not use FEC for either predictive health or growth performance indicators.

In the present study, cyathostomin types A (63%) and C (19.5%) predominated, a distribution consistent with national and international reports, which show type A as the most frequent (50–75%), followed by types D and C, with regional variations. In Paraná, Brazil, type A accounted for 62% of samples, D for 25.3%, and C for 5.7%. Coproculture and L3 identification confirmed a stable parasitic fauna on the studied farms. This technique remains a practical and cost-effective tool for monitoring equine parasite communities and detecting selective pressures associated with anthelmintic use. Reduced biodiversity and predominance of type A may indicate emerging drug resistance [29].

Other larval types—B, E, F, G, *Gyaloccephalus capitatus*, and *Posteriostomum spp.*, were rare (<3%). These results align with previous studies [30], confirming that cyathostomin populations in horses are typically composed of a few dominant species [28,29]. The observed diversity reinforces the heterogeneous yet predictable nature of equine parasite communities, which are usually dominated by a few taxa, regardless of location or management. L3 characterization thus remains essential for understanding parasite ecology and for designing region-specific control programs [28–30].

The correlations found between FEC and climatic variables suggest that precipitation, in particular, may have influenced

parasite dynamics, although not sufficiently to establish strong predictive relationships or create a warning system. Ecological models show that humidity favors larval survival, whereas drought reduces persistence [5,28]. Nevertheless, such models do not fully capture the complexity of production systems, underscoring the need for management strategies tailored to local climatic conditions. Temperature and moisture significantly impact egg hatching and larval development, with optimal development occurring between 25 °C and 33 °C. In contrast, freezing or desiccation drastically reduces larval yield. L1 and L2 larvae are especially vulnerable, whereas L3 can persist for months within intact fecal pellets [5]. The retrospective Brazilian study reported that FEC for *Parascaris spp.* and strongyles varied seasonally, with higher values in summer and lower in winter, confirming the influence of climate on parasite dynamics [13]. The results of the present study align with this pattern, highlighting that climatic variables interact with nutritional and management factors, rather than acting in isolation. Integrating environmental and parasitological data is therefore essential for a comprehensive understanding of infection dynamics.

Simulation studies further indicate that climate and seasonality influence the development of anthelmintic resistance. Drug resistance evolved more rapidly when treatments are applied in the spring under temperate conditions, as surviving worms contaminated pastures throughout the entire grazing season. Conversely, selective treatment in early spring delayed the development of resistance in colder regions [31]. In subtropical areas, seasonality has a minor influence on the advantage of selective therapy. Collectively, these findings demonstrate that FEC must be interpreted within environmental and climatic contexts, as temperature and rainfall patterns significantly impact parasite survival, clinical expression, and the sustainability of control practices. We consider these epidemiological and seasonal factors to be critical for field clinicians who need to base their decisions on high and low parasite transmission rates.

Foals of both sexes showed progressive body growth. These results align with those observed in Thoroughbred foals [32] during the first 13 months [9]. Foals raised in Brazil averaged 397.8 kg and 150.6 cm at 18 months, consistent with other breed standards [12]. These findings are similar to those in Kentucky (USA), where Thoroughbred foals reached an average of 250 kg at 6 months (43% of adult weight) and 350 kg at 12 months (61%) [9]. Despite the use of suppressive antiparasitic treatment every 4–8 weeks in the above studies, body performance was comparable to that observed in the present results, with practically no anthelmintic use. Similar growth rates have also been reported in India [10].

Under natural infection and minimal deworming, nutritional management and animal welfare were found to be decisive in maintaining satisfactory performance. Free access to pasture and concentrate supplementation likely supported optimal growth. High-quality pasture in the spring has been shown to improve body development in horses [10]. In contrast, diets high in starch and low in fiber may predispose horses to metabolic disorders such as laminitis and insulin resistance, reinforcing the value of balanced nutrition [33].

The comparison between body development and FEC revealed that foals with high FEC (>1,000 EPG) achieved

expected growth rates, suggesting that natural infection did not negatively impact performance. These findings support the hypothesis that within the observed range, FEC did not affect growth performance, indicating that monthly weight and height can serve as complementary parameters in equine health assessments [12,13]. The OR analysis revealed that foals with high FEC were also less frequent among treated animals, demonstrating reduced infection risk in this group. However, treatments were primarily based on clinical signs, such as diarrhea or mild colic, rather than on fixed FEC thresholds. This contrasts with studies that used specific intervention limits—for instance, 200 EPG [17,34,35]. Monitoring studies show that selective treatment markedly reduced drug use in only 34.7% of horses when they reached the 200 thresholds [36]. In Sweden, national monitoring revealed that 59% of horses did not require treatment under FEC-based protocols [17]. Nevertheless, FEC may not accurately reflect actual parasite burdens, as host immunity and physiological regulation can also influence egg production [37].

Higher FEC values were recorded in foals aged 13–15 months, matching patterns observed elsewhere. In Kentucky, untreated foals around 12 months exhibited higher counts than younger ones [31]. An extensive Brazilian study confirmed that young horses (≤ 2 years old) shed three times as many eggs as adult horses [13]. Similarly, a German study found that the mean strongyle FEC was above 800 in foals and yearlings. In contrast, adults averaged below 200 EPG, confirming that young animals are major contributors to environmental contamination and herd transmission [31]. Although avoiding systematic treatment helps prevent drug resistance, failure to treat high-risk age groups may compromise welfare and increase pasture contamination. Therefore, a question has arisen regarding the adoption of behavior and clinical protocols for foals and how that would contribute to higher larval concentrations in subsequent seasons.

The adoption of behavioral/performance protocols for horses enabled a more precise understanding of the relationships among welfare and parasitism. In the present study, the farm protocol has been in place for the past six years, with no significant changes or adverse events. Thus, integrating these protocols improved the interpretation of host responses to parasitism and guided management strategies. From another perspective, the longer the protocol is applied, the more resilient and less at risk in terms of welfare [38] the herd will ultimately become.

It is known that larval concentration is regulated by biotic and abiotic factors. Thus, considering that eggs are degraded by fermentation and light exposure on pasture or ingested at different free-living stages, a considerable number of larvae are removed before reaching the infective stage. It is also assumed that behavior-based monitoring does not lead to a significant increase in transmission levels, as animals reach immune maturity at an earlier age. Therefore, a long-term study would be necessary to confirm this hypothesis, including data on farm management, immune-specific status [39] (validating for South America), climate, and seasonal conditions to determine the pattern of egg shedding

among untreated animals and, consequently, the available larval risk to young foals.

In the present study, only four animals were treated, compared with standard blank regimens with 45–60 days' intervals (150–170 doses/10 months) [40], representing a >97% reduction. In this sense, the identification of more tolerant hosts is also a positive outcome of the study. A recent genome-wide association study (GWAS) identified genomic regions associated with FEC in naturally infected adult and young Thoroughbreds. The data accounted for up to 2.86% of the additive genetic variance. Candidate genes, such as ABCC4 and CD180, were associated with immune functions, including dendritic cell migration and Toll-like receptor signaling, providing new genomic evidence that connects host immunity to parasite egg shedding and resilience [11]. Although preliminary, this is the first GWAS study to cover horse genomics and FEC as a risk factor in mares and their foals.

Beyond biological factors, economic considerations play a central role in sustainable management. Cost analyses of FEC-based protocols with a 200-EPG threshold indicate that three group screenings per year (February/March, June/July, and September/October) effectively guide treatments. Under such programs, only 16–20% of horses require treatment per screening, plus one mandatory moxidectin-praziquantel treatment in December. This season-based approach drastically reduces the number of treatments compared to suppressive regimens, while FEC-based therapy lowers costs by approximately 36.7% [41]. The protocol using behavioral and clinical interventions achieved a much greater reduction, with no compromise to horse health.

These outcomes align with reports of reduced drug use and costs [17,19]. The benefits of such approaches increase when parasite control is viewed holistically, taking into account environmental sustainability and animal welfare. Economic models show that selective treatments can cut anthelmintic costs by up to 80%, and simplified testing, such as pooled fecal analysis, may further reduce costs while maintaining effective control [42]. Environmentally, limiting chemical interventions reduces antiparasitic residues in soil and water, mitigating ecotoxic risks under the One Health framework [43]. In this sense, parasiticides can contaminate ecosystems and harm non-target species, making the reduction of their use critical.

From a welfare perspective, selective treatment reduces the frequency and duration of handling, causing less stress for the horses. It is known that horses exposed to stressors exhibit elevated fecal cortisol metabolite levels, with variations linked to transport, management, and environmental conditions [44]. The present data are sufficiently robust, as the animals belonged to the same breed and age category and were maintained under uniform environmental conditions and daily management. Although the protocol should be applied across other farm conditions and animal breeds, these findings support farm-specific programs that integrate behavior analysis, horse performance, and resilience to parasites.

5. Conclusion

A wide variation in fecal egg counts was observed among foals, yet no significant effect on body growth was detected under the present conditions. The consistent growth likely reflects the farm's high standards for nutritional and health management. These findings support an integrative approach to parasite control that considers both FEC and overall animal condition. Despite the limited sample size and study duration, this preliminary individualized decision-making assessment offers veterinarians and animal breeders valuable insights into resilience-based management strategies to promote sustainable equine health and welfare.

Authors' Contributions

E.P.: Conceptualization, literature review, data analysis, writing—original draft. I.R.N. and A.J.F.: Conceptualization, data analysis. E.P. and U.Y.: Literature review, critical review. M.B.M.: Validation, supervision, critical review, writing—review & editing, final approval of the manuscript.

Data Availability

All data analyzed in this study are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no commercial or financial conflicts of interest.

Ethical Approval

The project was approved by the Ethics Committee on the Use of Animals in the Agrarian Sector at the Federal University of Paraná (CEUA/UFPR); Approval No. 2014/026.

Declaration of Generative AI and AI-Assisted Technologies

The authors declare that no generative AI or AI-assisted technologies were used in the collection, analysis, or interpretation of data during the preparation of this manuscript.

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