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The use of body growth and kinship data from 16 generations for predicting Thoroughbred performance

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ABSTRACT

Thoroughbred horses have been intensely raised for their athletic potential that is correlated with morphological parameters (i.e., body weight - BW, and withers height - WH). Optimum and consistent body development is aimed, but excessive growth rates may lead to the development of orthopedic diseases. This study aimed to generate growth rate curves and prediction models of Thoroughbred horses by analyzing BW and WH data collected monthly over 16 years of 378 animals (23.6 animals/year). The animals were checked from birth to 18 months (160 colts and 181 fillies) on a farm in the south of Brazil. A prediction performance ARIMA model was developed based on the BW and WH of the foals using a maximum and minimum range of 7320 observations. BW and WH were 54,1 kg and 102,5 cm at birth and 397,8 kg and 150,6 cm at 18 months of age, respectively. No differences were found between sex at any age. Moreover, we have established a nonlinear function for the growth curve and on average, foals were expected to get 7.4 times heavier and 1.5 times taller when animals were fully grown. Males showed greater BW uniformity than females, as females had a lower minimum BW than males. Significant statistical differences ($P < 0,05\%$) were reported for BW and WH of foals between pairs of sires highlighting the kinship (paternal) effect on the animals' development. Seventy-two pairs of stallions showed statistical relevance for BW and 91 for WH. The ARIMA model produced a linear trend of BW and WH for the forecasted years. In conclusion, we recommend that careful sire selection and adequate health (i.e., parasite control, vaccination), and nutrition strategies must be adopted to achieve superior body growth as estimated by the predicting model (positive scenario). The present protocol shall be used in studs worldwide to monitor horse development. The spreadsheet is available on request to the corresponding authors.

1. Introduction

Thoroughbred horses have been intensely selected for their athletic phenotypes, always seeking to exceed results on the tracks in short, medium, or long-distance races. Subjective information is commonly used by racehorse buyers and trainers to allocate horses where they would have their best performances (Schrurs et al., 2022). Data have been established to correlate morphological parameters and sports performance. Withers height (WH) and heart girth were moderated and favorably correlated to the numbers of earnings per start, according to the Standard Starts Index (SSI) of Thoroughbred female yearlings. WH showed a positive trend toward the association with the winnings of males (Smith et al., 2006). Similar findings were reported by Brown-Douglas et al. (2009) stating that taller, but not heavier, young growing horses were likely to be more successful as athletes.

The comprehension of the growth progress of individuals can directly influence changes in the management of the stud and the welfare of the animals. In this matter, birth weight significantly influences adult body weight in Thoroughbreds (Brown-Douglas et al., 2005; Morel et al., 2007), and measurements collected from foals in the first month of life express the horse's genetics and naturally expected size (Brown-Douglas et al., 2009; Huntington et al., 2020). From weaning to yearling, seasonal factors had the greatest interference with growth rate, as demonstrated by Dias de Castro et al. (2021), and Brown-Douglas et al. (2005). The former authors stated that the body development of foals was markedly influenced by the month of birth, probably because of the availability and quality of grazing pasture. Moreover, measurements obtained over time (1 year or more) should validate how the environment can influence the size of the animals (Brown-Douglas et al., 2009).

Slow growth rates may result in unformed and immature horses but growing a foal too fast or even a fluctuating growth rate may increase the risk of developing orthopedic diseases (DOD) (Onoda et al., 2013; Pagan, Jackson, 1996). Savage et al. (1993) overfed foals with a diet 130% higher in energy intake, significantly altering their growth rate and increasing the incidence of dyschondroplasia joint lesions. Osteochondrosis is a clinically important DOD and its manifestation can be influenced by the fluctuation of nutrient intake, as it leads to growth rate variation and challenges endochondral ossification (Huntington et al., 1999; Barneveld and van Weeren, 2020).

Body development curves are also the result of the interaction between an individual's genetic makeup and the surrounding environment (Fitzhugh, 1976; Kuhi et al., 2022). The genetic composition, or kinship, influences the horse's running capacity since it impacts characteristics linked to the animals' morphological conformation (Brown-Douglas et al., 2009). Heritability estimates are necessary for optimal selection processes when looking for selecting body performance (Hintz et al., 1978). Structure traits, such as WH and body weight (BW) have quite high estimates of heritability, as demonstrated by Faria et al. (2004), and Saastamoinen (1990). Foal birth weight is directly correlated to placental weight (Elliott et al., 2009), which is affected by the kinship theory of genomic imprinting i.e., an epigenetic phenomenon that causes the unequal expression of only one copy of a gene (either maternal or paternal) (Wolf, Hager, 2006). Mare nutrition and reproduction management are more sensitive in the immediate postpartum period, influencing the foal's initial growth and health (Brown-Douglas et al., 2005; Morel et al., 2007). Following that, nursing foals depend largely on the amount of milk produced by their mares, whose yield is highly correlated to their nutritional status (Pagan et al.,1996; Staniar et al., 2004).

From six months of age, when weaning usually occurs, the foal's growth is directly affected by external environmental characteristics (i.e., management, nutrition, and health care) instead of seasonal factors (Kocher, Staniar, 2013; Fitzhugh, 1976).

The mammalian growth pattern is usually described as flexible sigmoid curves and a more detailed characterization could allow researchers and breeders to better design strategies for maintaining an adequate growth rate (Fitzhugh, 1976; Kocher et al., 2013). Growth of Thoroughbred horses has been largely documented as they show a fast development in the first month of life with a maximum average daily weight gain (DWG) that often exceeds 1.5 kg/day. From this, there is a gradual decrease until the foals reach up to 10 months of life. DWG would typically increase after 11 months until the horse reaches maturity when growth finally comes to an end (Brown-Douglas et al., 2009; Kavazis and Ott (2003). WH, BW, heart girth, and cannon bone of many horse breeds (Lusitano, Quarter Horses, Arabian, Mangalarga, and Campolina horses) were evaluated under different managing conditions. A clear sexual dimorphism was observed in all breeds with high average weight and height values for colts at any age (Cunningham, Fowler, 1961; Fradinho et al., 2016; Manso Filho et al., 2014; Teixeira et al., 2021). Assuming that the nutritional requirement of the animals is met according to their age and size, foals raised on pasture and fed high starch diets tend to get similar growth results (Brown-Douglas et al., 2005; Fradinho et al., 2016; Manso Filho et al., 2014; Teixeira et al., 2021).

Due to differences between the Northern and Southern hemispheres, animals may be influenced by distinct climates and plant diversity, having access to a variety of nutrition levels (Brown-Douglas, Pagan, 2009; Morel et al., 2007). Different foal growth rates were studied between southern and northern countries, and between foals and yearlings with different nutritional levels. In the southern hemisphere, autumn-born foals had higher post-weaning growth rates than spring-born foals (Brown-Douglas et al., 2005); but in the northern hemisphere, the opposite happened, where foals born during winter had lower birth weight and lower daily weight gains than those born in the summer (Pagan et al., 2009). Considering that the nutrient requirements of an animal are determined from its BW and that most breeders do not make regular adjustments on the horses' diets (M. Molento, personal observation), there is a need to establish individual growth curves that would allow estimating the weight and height of the animals to meet their demand for nutrients as well as identify changes in the expected growth rate at any age category. The present study analyzed BW and WH data of 378 Thoroughbred foals and yearlings obtained over 16 generations (2002-2017) in the south of Brazil. The data was used to generate a forecast model analysis for body growth.

2. Material e Methods

2.1. Animals, stud management, and body measurements

Data on WH and BW of 378 animals were collected from June 2002 to April 2017 (average of 24 animals/year) from a Thoroughbred breeding stud in the metropolitan area of Curitiba, Paraná, Brazil. BW was assessed using a mechanical scale and WH was measured using a hypsometer. Both measurements were performed monthly, the first took place within the first 24 h of the foal's life and the former at the last month of the horse at the farm (approx. 18 - 22 months of age). Data were obtained by the local veterinarian and reviewed by two other veterinarians. We processed 7320 evaluations for BW and WH.

All animals were born and maintained on the same farm with similar management and nutrition. Foals were kept in groups of 10 - 12 animals with their mothers until they completed 6 months of age. The weaned foals remained on pasture in single-sex groups, covered with ryegrass (*Lolium multiflorum*), and white clover (*Trifolium repens*) during the winter and mixed pastures of Bahia grass (*Paspalum notatum*), and Dallis grass (*Paspalum dilatatum*) during the summer. The animals were supplemented twice daily with a pelleted diet, oat, mineral salt, and Bermuda grass (*Cynodon dactylon*) hay according to the animal's age and weight. Water was available ad libitum.

2.2. Prediction performance ARIMA model

A nonlinear regression function fitting the data was made and a forecast autoregressive integrated moving average (ARIMA) model was constructed. The forecast graphs were prepared using Microsoft Excel for the average of BW and

WH at 6, 12, and 18 months of age. For the composition of forecast graphs, data from 2002 to 2014 (13 generations) were used. Data from 2007 were not used due to inconsistency of information.

2.3. Statistical analysis

A descriptive statistical analysis was performed using a boxplot of individual profiles of each animal and a curve containing the mean and confidence interval for the BW and WH of all animals was established. Data from 2002 to 2017 were first analyzed with the Lilliefors test to determine population distribution. The non-parametric test Kolmogorov-Smirnov was performed to test the null hypothesis, confirming that the two groups (male and female) had similar distributions. The non-parametric ANOVA (Kruskall-Wallis) was performed to identify the paternal effect on the foal's BW and WH. Finally, a multiple comparison Nemenyi test was applied to pairs of sires. A common confidence interval was used for the graphs, and missing data were corrected by interpolation. Statistical analysis was performed using the R software version i386 4.0.0 (www.r-project.org.br) and GraphPad Prism version 9.5.0.730 (San Diego, USA) (www.graphpad.com).

3. Results

There was no statistically significant difference (P > 0,05) between males and females for BW and WH (Figure 1). The average of all foals for BW and WH was 54,1 kg and 102,5 cm at birth, increasing to 397,8 kg and 150,6 cm at 18 months old, respectively. Although some fillies were taller and heavier at birth than colts, they reached similar average BW and WH after 18 months (Figure 1). Fillies always had a wider amplitude of measurements at 6 months and at 18 months of age when compared to the narrower data from the colts (Figure 1a and 1b). Figure 2 exhibits the data distribution and the amplitude of BW and WH by age (date) and sex, from birth (day 0) to up to 25 months old horses from 16 generations. Males showed greater BW uniformity (little less dispersal) than females, as females had a lower minimum BW than males (Figure 2).

Figure 1 *– Boxplot of the average and standard error of (A) body weight (BW, kg) at birth and 18 months of age, and (B) withers height (WH, cm) of females and males from 16 generations of Thoroughbred horses (n = 378) in southern Brazil.*
Obs.: Similar letters within boxplots indicate that there is no statistical difference (P > 0,05).

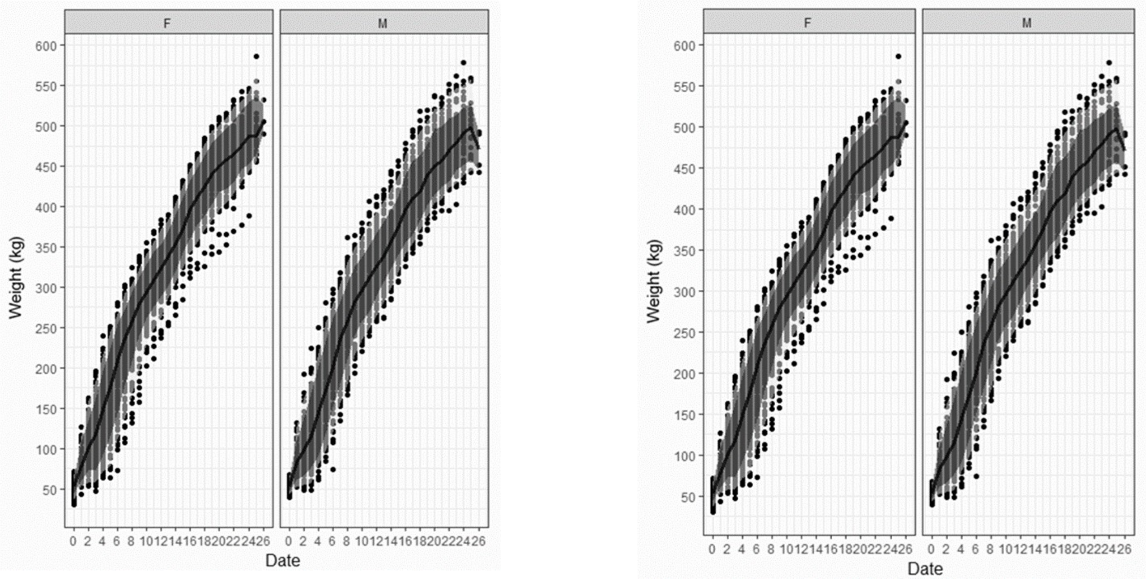


__Figure 2__ – Dispersion of body weight and withers height data by age (date in months) and sex (female – F, and male – M) from birth (day 1) to up to 25 months of age from 378 Thoroughbred horses from 16 generations in Brazil. The black line represents the average values; the black dots indicate the dispersion of the data. The light gray dots represent the 80% confidence interval. The dark gray central area represents the 95% confidence interval.

Progenies were bred from 54 stallions and 103 mares. The sires had on average 6.3 foals of which 16 (29,6%) produced only one foal (Figure 3). Stallions were chosen based on national and international sports performance during previous years. Mares had 228 foals and 66,9% of the new foals were born from couples that had only bred once. It was observed a statistically significant difference ($P < 0.05$) between the BW and WH of the foals according to their paternal affiliation (Table 1). The data also indicate a significant effect and interaction of kinship. Seventy-two pairs of stallions showed statistical relevance for BW and 91 for WH (Table 1).

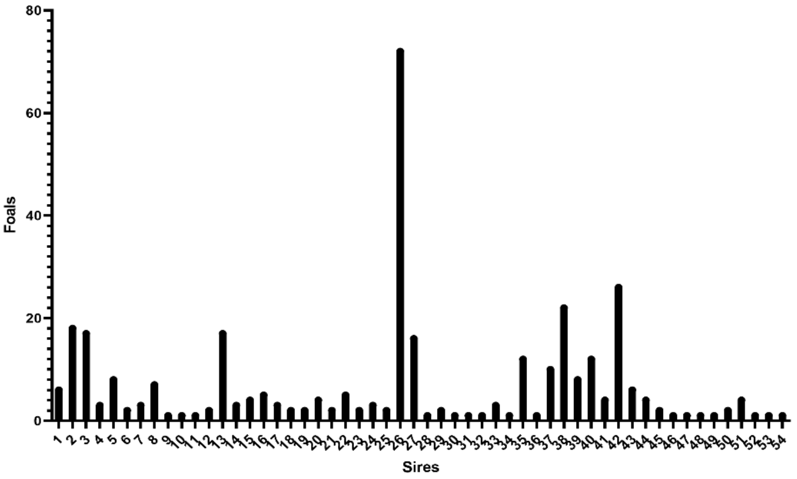
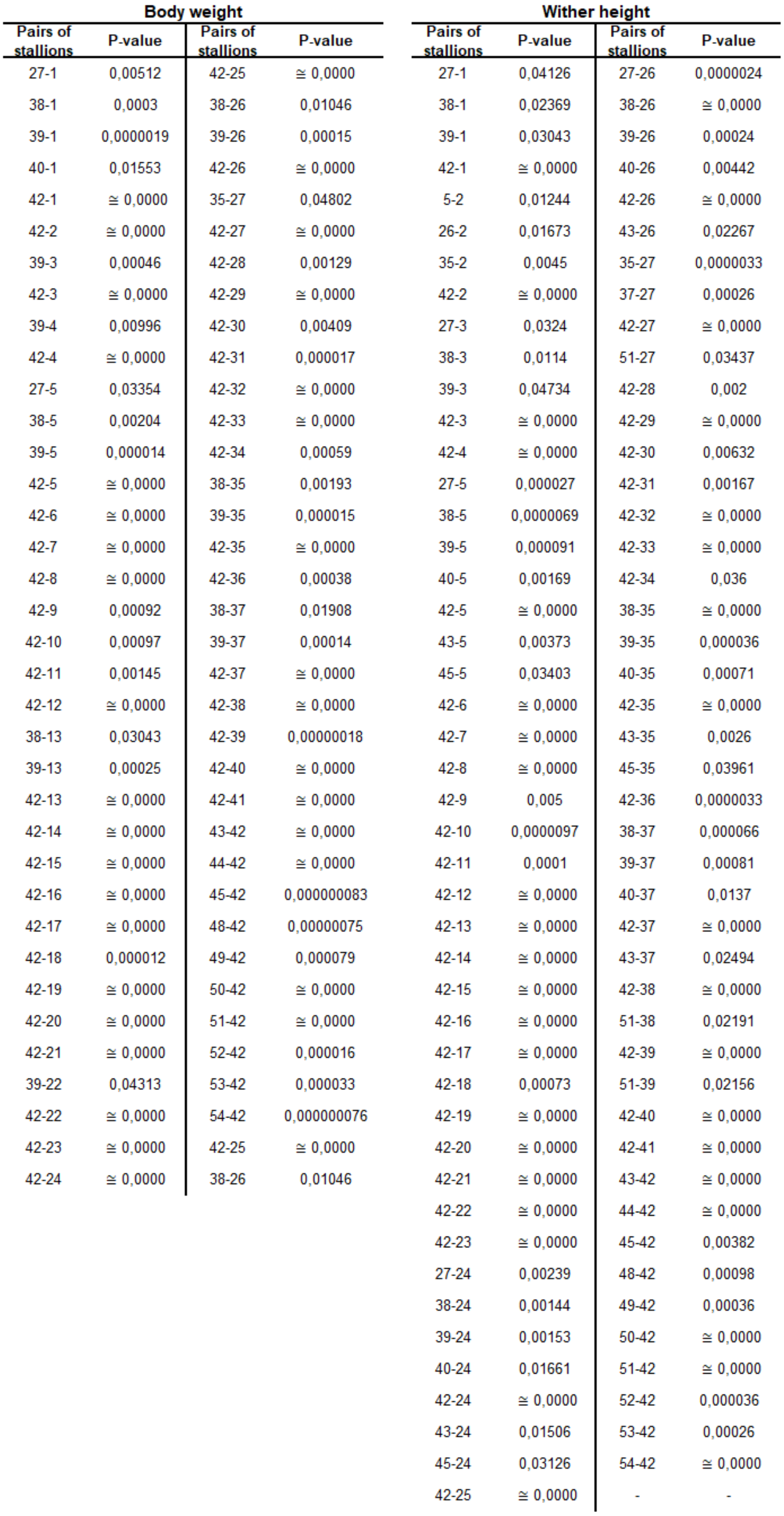


Figure 3 – Number of foals (n = 378) born per individual Thoroughbred sire, ranging from 1 to 72 animals from 2002 to 2017 in Brazil.

The average DWG of all foals was 880.4 g in the first month and 483.4 g at 18 months of age (Figure 4) keeping a wide deviation. The curve is characterized by rapid body growth in the first six months whilst the curve beyond this age was deflecting gradually until approximately 16 to 17 months of age. The average DHG peaked when animals were 6 months old to approximately 4.4 cm/month (approx. 0.15 cm/day) (Figure 5). From there, both fillies and colts had slow growth until reaching 18 to 22 months of age.



Body weight

Pairs of stallions	P-value	Pairs of stallions	P-value
27-1	0,00512	42-25	≅ 0,0000
38-1	0,0003	38-26	0,01046
39-1	0,0000019	39-26	0,00015
40-1	0,01553	42-26	≅ 0,0000
42-1	≅ 0,0000	35-27	0,04802
42-2	≅ 0,0000	42-27	≅ 0,0000
39-3	0,00046	42-28	0,00129
42-3	≅ 0,0000	42-29	≅ 0,0000
39-4	0,00996	42-30	0,00409
42-4	≅ 0,0000	42-31	0,000017
27-5	0,03354	42-32	≅ 0,0000
38-5	0,00204	42-33	≅ 0,0000
39-5	0,000014	42-34	0,00059
42-5	≅ 0,0000	38-35	0,00193
42-6	≅ 0,0000	39-35	0,000015
42-7	≅ 0,0000	42-35	≅ 0,0000
42-8	≅ 0,0000	42-36	0,00038
42-9	0,00092	38-37	0,01908
42-10	0,00097	39-37	0,00014
42-11	0,00145	42-37	≅ 0,0000
42-12	≅ 0,0000	42-38	≅ 0,0000
38-13	0,03043	42-39	0,00000018
39-13	0,00025	42-40	≅ 0,0000
42-13	≅ 0,0000	42-41	≅ 0,0000
42-14	≅ 0,0000	43-42	≅ 0,0000
42-15	≅ 0,0000	44-42	≅ 0,0000
42-16	≅ 0,0000	45-42	0,000000083
42-17	≅ 0,0000	48-42	0,00000075
42-18	0,000012	49-42	0,000079
42-19	≅ 0,0000	50-42	≅ 0,0000
42-20	≅ 0,0000	51-42	≅ 0,0000
42-21	≅ 0,0000	52-42	0,000016
39-22	0,04313	53-42	0,000033
42-22	≅ 0,0000	54-42	0,000000076
42-23	≅ 0,0000	42-25	≅ 0,0000
42-24	≅ 0,0000	38-26	0,01046

Wither height

Pairs of stallions	P-value	Pairs of stallions	P-value
27-1	0,04126	27-26	0,0000024
38-1	0,02369	38-26	≅ 0,0000
39-1	0,03043	39-26	0,00024
42-1	≅ 0,0000	40-26	0,00442
5-2	0,01244	42-26	≅ 0,0000
26-2	0,01673	43-26	0,02267
35-2	0,0045	35-27	0,0000033
42-2	≅ 0,0000	37-27	0,00026
27-3	0,0324	42-27	≅ 0,0000
38-3	0,0114	51-27	0,03437
39-3	0,04734	42-28	0,002
42-3	≅ 0,0000	42-29	≅ 0,0000
42-4	≅ 0,0000	42-30	0,00632
27-5	0,000027	42-31	0,00167
38-5	0,0000069	42-32	≅ 0,0000
39-5	0,000091	42-33	≅ 0,0000
40-5	0,00169	42-34	0,036
42-5	≅ 0,0000	38-35	≅ 0,0000
43-5	0,00373	39-35	0,000036
45-5	0,03403	40-35	0,00071
42-6	≅ 0,0000	42-35	≅ 0,0000
42-7	≅ 0,0000	43-35	0,0026
42-8	≅ 0,0000	45-35	0,03961
42-9	0,005	42-36	0,0000033
42-10	0,0000097	38-37	0,000066
42-11	0,0001	39-37	0,00081
42-12	≅ 0,0000	40-37	0,0137
42-13	≅ 0,0000	42-37	≅ 0,0000
42-14	≅ 0,0000	43-37	0,02494
42-15	≅ 0,0000	42-38	≅ 0,0000
42-16	≅ 0,0000	51-38	0,02191
42-17	≅ 0,0000	42-39	≅ 0,0000
42-18	0,00073	51-39	0,02156
42-19	≅ 0,0000	42-40	≅ 0,0000
42-20	≅ 0,0000	42-41	≅ 0,0000
42-21	≅ 0,0000	43-42	≅ 0,0000
42-22	≅ 0,0000	44-42	≅ 0,0000
42-23	≅ 0,0000	45-42	0,00382
27-24	0,00239	48-42	0,00098
38-24	0,00144	49-42	0,00036
39-24	0,00153	50-42	≅ 0,0000
40-24	0,01661	51-42	≅ 0,0000
42-24	≅ 0,0000	52-42	0,000036
43-24	0,01506	53-42	0,00026
45-24	0,03126	54-42	≅ 0,0000
42-25	≅ 0,0000	-	-

Table 1 *– Post hoc comparison between individual pairs of stallions* (n = 54) on body weight and withers height of 378 Thoroughbred foals born between 2002 and 2017 in Brazil. * Only significantly different pair-wise p-values (P < 0,05) are shown.*

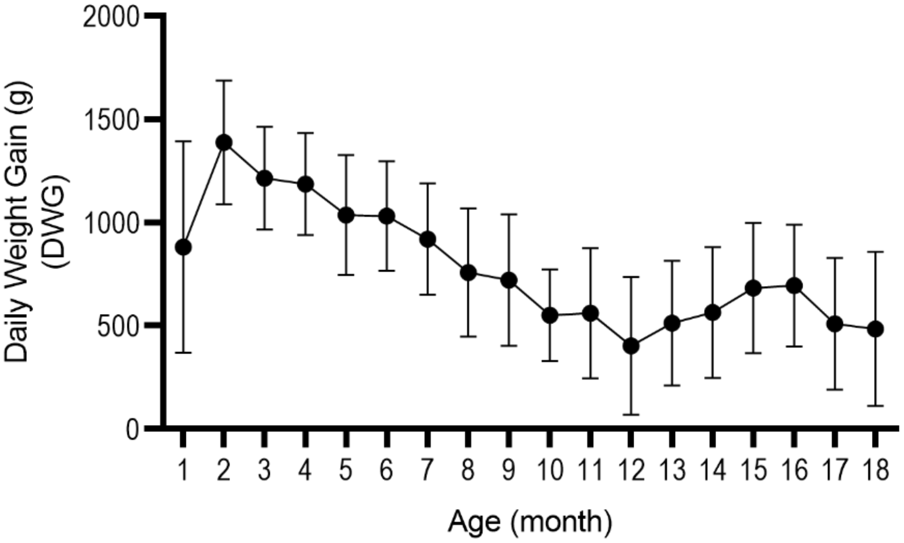


Figure 4 – Average (dot) and standard deviation (bars) of daily weight gain (DWG) from 1 to 18 months old of 378 Thoroughbred horses from 16 generations in Brazil.

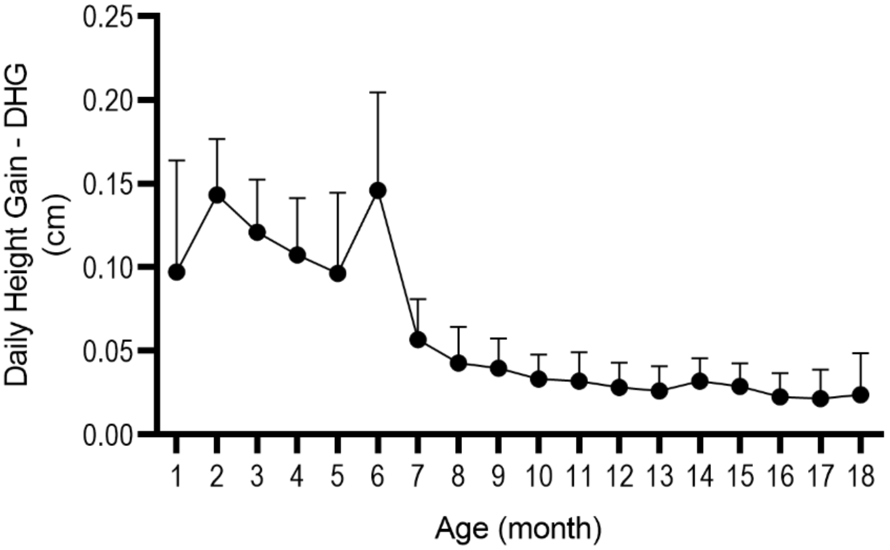


Figure 5 *– Average daily height gain (DHG) and standard deviation from 1- to 18-month-old of 378 Thoroughbred horses in Brazil.*

The distribution of the data series by year and over the years allowed us to establish a forecast model. The prediction tool was used to estimate the WH and BW of foals for another six years – from 2014 to 2020 (Figure 6A-C and 7A-C). Figure 6 shows the average and the predicted BW at 6, 12, and 18 months. The upper lines indicate the upper confidence limit (positive scenario – heavier animals) for BW, and the bottom lines indicate the lower confidence limit (negative scenario – thinner animals).

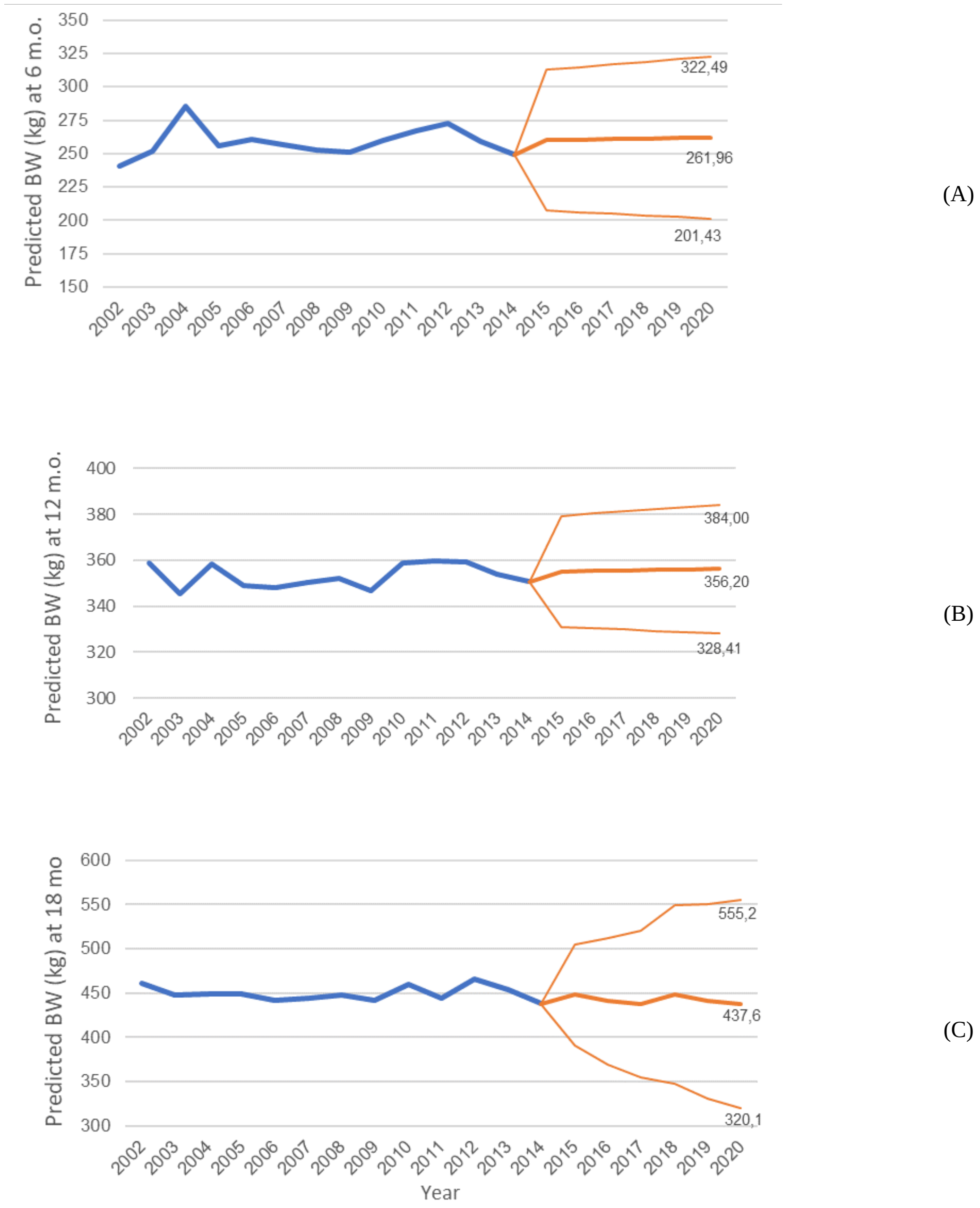


Figure 6 – *Average (blue line) and predicted body weight (central orange line) at 6, 12, and 18 months of age using a nonlinear mixed sigmoid growth model on 378 Thoroughbred horses raised in Brazil. The upper orange line indicates the upper confidence limit (positive scenario), and the lower orange line indicates the lower confidence limit (negative scenario).*

Figure 7 shows the average and the predicted WH at 6, 12, and 18 months of age. The upper lines indicate the upper confidence limit (positive scenario – taller animals), and the bottom lines indicate the lower confidence limit (negative scenario – shorter animals).

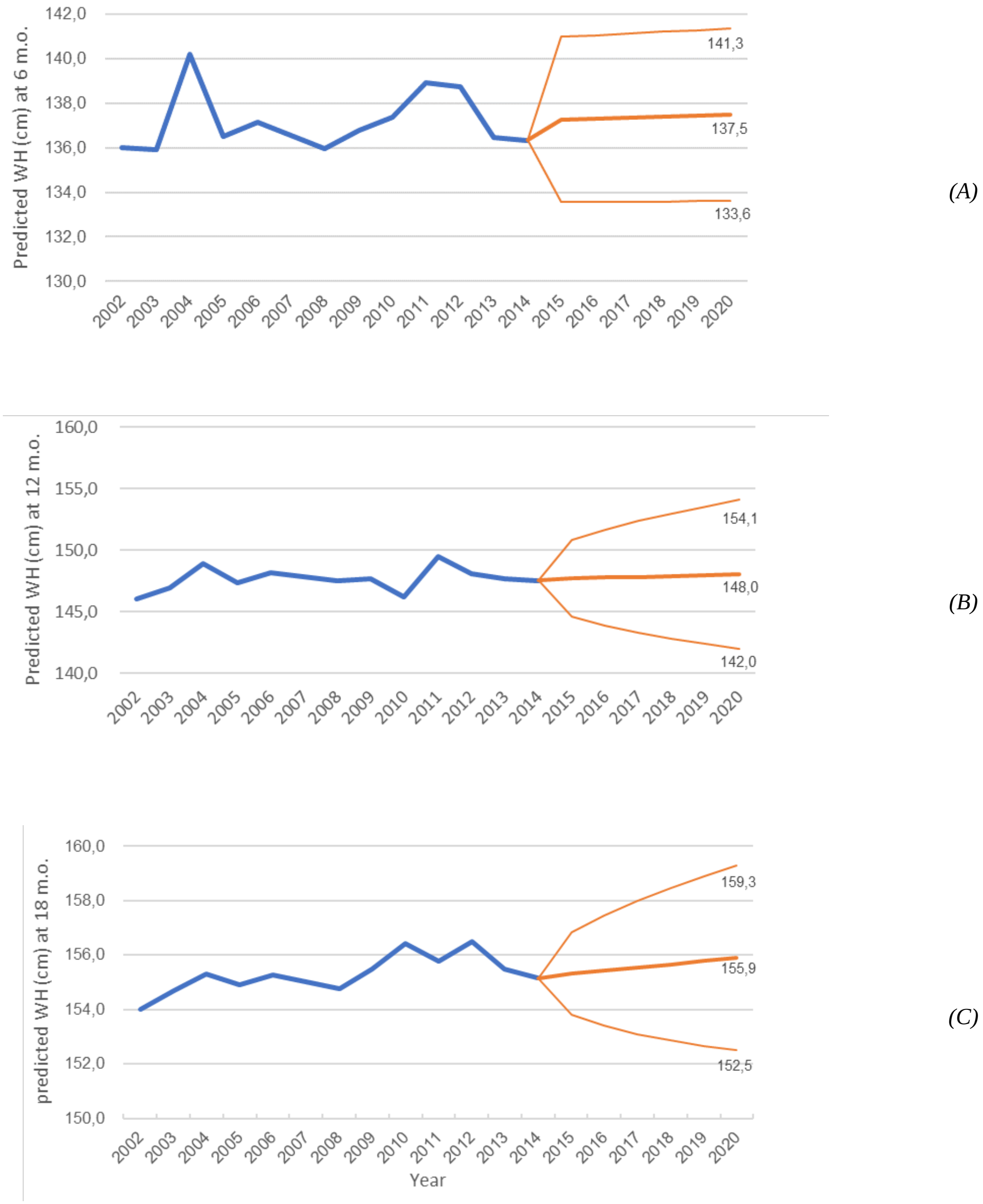


Figure 7 *– Average (blue line) and predicted withers height (central orange line) at 6, 12, and 18 months of age using the nonlinear mixed sigmoid growth model on 378 Thoroughbred horses raised in Brazil. The upper orange line indicates the upper confidence limit (positive scenario), and the lower orange line indicates the lower confidence limit (negative scenario).*

4. Discussion

The present data enabled the comprehension of the BW and WH when analyzing 378 thoroughbred foals in a temperate region of Brazil. This knowledge can directly influence changes in health and nutrition management and reproduction plans, improving the welfare of the animals. Monitoring and comparing the BW and WH of animals between years has allowed us to establish a prediction model for the growth rate of foals. The model may also be used by other horse breeds in similar or distinct geographical and climate areas.

There were no significant differences between male and female parameters, so data were combined for further analysis. At birth BW and WH were similar to that reported by Kavazis and Ott (2003) in Florida, and Jelan et al. (1996) in Ireland. Brown-Douglas and Pagan (2009) reported heavier and higher foals at all ages (birth, and 6, 12, and 18 months old) in the USA, Australia, England, India, and New Zealand than the present population. Small horses do not indicate low performance, as 40% of elite winners weighed below the average in 3734 American Thoroughbred racing (Brown-Douglas et al., 2009). Moreover, the overall percentage increase of BW and WH from birth to 18 months of age was similar among all the populations, in Brazil and the world. Differences at the indicated ages were probably a consequence of foal birth weights, which are affected by maternal and paternal factors (i.e., gene expression) during gestation (Dini et al., 2021; Elliott et al., 2009; Klewitz et al., 2015; Wolf, Hager, 2006).

The maternal effect on the foal's birth weight reflects the balance between placental efficiency, the size of the mare, and maternal-fetal contact (Klewitz et al., 2015). The adequate nourishment to the fetus through the placenta is controlled by a maternal allele expression that maintains the health of both the foal and the mare (Wolf, Hager, 2006). Elliott et al. (2009) demonstrated that for every 1 kg increase in placental weight (up to 6.5 kg) the weight of the foal can increase to 4.5 kg. Mare's uteroplacental blood flow, which is associated with fetal growth and metabolic demands, presented a moderate correlation to birth weight (Klewitz et al., 2015). Mare parity rather than age also presented a positive correlation to the BW at birth (Elliott et al., 2009; Klewitz et al., 2015). Multiparous mares also presented greater placental surfaces and heavier foals than maiden mares (Elliott et al., 2009; Hintz et al., 1978). Paternally inherited genes can increase fetal growth, controlling fetal metabolic and protein biosynthesis despite the maternal fitness cost (Dini et al., 2021). The ideal reciprocal paternal and maternal gene interaction is still not achievable since the role of genes involved in placental development has not been fully elucidated. Dini et al. (2021) in a very elegant study determined seven ligand-receptor interactions that correlated in their expression patterns throughout gestation. From these ligand-receptor interactions, CALM2:ABCA1, CALM2:INSR, and IGF2R:IGF2 had a different parent (maternal:paternal expression) of origin. The authors found four interactions with only paternal expression (DLK1:NOTCH4, IGF1:IGF1R, IGF1:INSR, and IGF2:INSR) present in different chromosomes. Thus, breeding strategies have been relying heavily on the phenotypic selection of previous performance traits and kinship (i.e., DWG, DHG, and body growth rates).

The DWG and DHG data did not show the expected international pattern in the first month, i.e., the fastest-growing rates (Brown-Douglas et al., 2005; Kocher, Staniar, 2013; Morel et al., 2007; Onoda et al., 2013; Pagan et al., 1996). The greatest growth rate was observed in the second month with an average of DWG and DHG similar to those described in the first month by Brown-Douglas; Pagan (2009) (1.4 kg/day and 4.4 cm/month, respectively). This difference was probably due to the stud management practices and the wide variation that occurs in growth and growth rates in the first month of the foals' life (Jelan et al., 1996; Staniar et al., 2004). As measures were not exactly taken on the 30th day of their life, the first measurement did not cover the entire same period observed in other trials (Brown-Douglas et al., 2005; Kocher, Staniar, 2013; Morel et al., 2007; Onoda et al., 2013; Pagan et al., 1996). From the second month onwards, both curves were within the expected pattern. As described by Pagan et al. (1996), a slow decrease in body weight until the 10th month with a peak in height growth rate at 6 months of age is accepted. This was followed by a slow increase in weight and height up to 16 to 18 months of age, reaching a plateau (young adult-size horse) after that.

The comparison between pairs of stallions showed that 16 of them had a statistically significant positive influence on the weight, and 18 on the height of their offspring. Foals born to stallion ID42 presented higher values of BW and WH over 41 other stallions. This particular north-American stallion sired several top-level runners in the US, Argentina, and Brazil figuring in the top ten ranking on the Brazilian general sire list (2019 to 2021) (ABCPCC, 2022). Even though previous studies on Brazilian Thoroughbred body growth are scarce, the data collected by Garcia et al. (2011), as well as ours, indicate that the average weight at birth and 18 months are lower than the world average BW and WH values (Brown-Douglas and Pagan, 2009). On the other hand, North American horses, especially those from Kentucky, presented higher average BW and WH. Consequently, it is expected that including horses descended from bloodlines from this region (i.e., Kentucky, etc.) will cause significant increases in BW and WH when compared to stallions living in other geographical areas and breeding with smaller mares.

High heritability (h2) estimates were obtained by Hintz et al. (1978), indicating a paternal effect of Thoroughbred sires over BW (h2 = 0.90) and WH (h2 = 0.88). Schroderus and Ojala, (2010) also estimated a high heritability for the same traits in Finnhorses and Standardbred foals. Even though, the values may have been slightly overestimated for this study as the majority of the foals were sampled only once. In our study circa 30% of the stallions produced only one foal, which is a limitation of the present data. The high magnitude of estimates of heritability for body growth must be considered in breeding programs to improve herds and reach optimum animal performance, health, and welfare (Faria et al., 2004; Hintz et al., 1978; Saastamoinen, 1990; Schroderus, Ojala, 2010).

However, this information must be cautiously interpreted. The overbred of some stallions, chosen by their outstanding racing performance may result in undesirable inbreeding effects, seen as a loss of heterogenicity (Hill et al., 2022; McGivney et al., 2020). The individual aptitude for race distance (i.e., phenotypic trait) has been associated with polygenic inheritance (Hill et al., 2022). As a consequence, genomic regions responsible for other biological functions have been indirectly selected during the development of Thoroughbred horses. Moreover, better results were not achieved by the resulting islands of homozygosity due to overbreeding (Colpitts et al., 2022; Hill et al., 2022, McGivney et al., 2020). A current approach for assessing inbreeding in individuals and populations has been named runs of homozygosity (ROH). The ROH protocol uses specific molecular information based on high-density single nucleotide polymorphism (SNP) arrays (Colpitts et al., 2022; Hill et al., 2022, McGivney et al., 2020). ROH is not subject to the same errors that pedigree is and ROH occurs in specific demographic processes that reduce effective population size, significantly affecting animal traits (Colpitts et al., 2022). In this line, for every 10% increase in the frequency of ROH, there was an estimated 7% lower probability of horses ever racing (Hill et al., 2022). Moreover, Santana et al. (2017) used an Illumina Equine SNP70 BeadChip chip to calculate the coefficient of ROH in 98 Thoroughbred horses from the same breeding stud in Parana. The data revealed proportions of segments in homozygosity of the genome containing 65,157 SNPs. The authors concluded that inbreeding coefficients derived from ROH can be useful for measuring inbreeding levels in horses. From the above ROH data, we can also compare Thoroughbred horses from the UK (TBUK), the USA (TBUS), and Brazil (TBBR). The mean ROH-based inbreeding coefficient (FROH) by length class showed to be highly similar (0.20, 0.19, and 0.21, respectively) among the three different countries. The mean number of ROH segments was 121 for TBUK, 119 for TBUS, and 95 for TBBR; and the lengths were 4.1, 4.1, and 4.8 Mb, respectively – also very comparable. All evaluations demonstrate a relatively recent inbred practice, indicating the low genetic variability of the populations, characterized by selective bottlenecking as animals are generally bred based on race performance.

The present trial was the first in Brazil to gather data from 16 generations to elaborate a forecast model that included maximum and minimum estimates of BW and WH (dependent values) according to foal age and kinship (predictors). The distribution of data over the years resulted in uniform growth curves suitable to the application of a non-linear regression model as a prediction tool. Modeling growth through mathematical functions allowed us to create a graphical representation that summarized the variation data over another six years – future scenarios. Forecast data presented two different expectations: above and below the average. These possible scenarios would be influenced by environmental and genetic factors (Beltrán et al., 1992; Gianola et al., 2014; Kuhi et al., 2022). The application of forecast models would also allow the regulation of food requirements, and the selection criteria in breeding programs (i.e., the choice of stallions and mares), as the prediction curves allow for the estimation of DWG and DHG (Brown-Douglas and Pagan, 2009; Elliott et al., 2009; Hintz et al., 1978; Pagan et al., 1996). Therefore, by using the present model, one could fine-tune potential decisions during the breeding year and in distinctive conditions.

The developed model based on the growth curves highlighted differences in growth parameters as the result of sire selection and probably nutritional conditions. Beltrán et al. (1992) used nonlinear regressions of weight data to predict mature weight in Angus cattle and evaluated the potential genetic and reproduction effects. Gianola et al. (2014) used a variety of mixed linear models to compute the genomic prediction to identify Jersey bulls with better-performance daughters/heifers. Bulls with future daughters with higher pregnancy rates were identified by a significant deviation from the early genomic transmitting ability. The presence of selected sires in the reference population helped to stabilize the predictions. The forecasting data can be used to determine which stallion or management technique to invest in, to plan future expenses over a given period, and to manage risk by having access to possible outcomes under different scenarios. Therefore, owners and breeders could directly improve from growth records data through applications that would allow them to interact with the graphs and decision-making process (KER Gro-Trac Equine Growth monitoring, 2023).

Foals and horses may benefit from forecasting models identifying individuals that are off the expected pattern allowing the investigation of the presumable underlying health causes i.e., deworming strategies (Bellaw et al., 2016). Low BW suggests low welfare, as it may be due to chronic conditions such as parasite infections, inadequate nutrition, or any other debilitating chronic diseases (Christie et al., 2006). Gastrointestinal parasitic diseases are one of the major health problems for horses, especially young foals and yearlings (Molento, 2005). Parasites are constantly controlled, which consist almost of parasiticidal treatments (Canever et al., 2013). Cyathostomins, known as small strongyles, are associated with non-lethal conditions and unspecific clinical signs (Bellaw et al., 2016; Reinemeyer et al., 2003). BW and body condition score (BCS) of heavily parasitized equids were used as evidence of the effectiveness of the adopted anthelmintic regimen, demonstrating the importance of monitoring these parameters in the identification of parasitic diseases (Bellaw et al., 2016; Matthee et al., 2002; Silva et al., 2016). The performance parameters (BW and BCS) can be used for the identification of suboptimal parasite controls and their impact on the health of young animals (Bellaw et al., 2016). It was also reported that health and nutritional conditions may be improved in donkeys as a result of adequate deworming programs (Molento and Vilela, 2021). However, no significant differences in weight gain and/or BCS were observed in young (Bellaw et al., 2016) or adult (Silva et al., 2016) animals fed at optimal nutrient requirements. Although not previously confirmed, we suggest that parasitic diseases may be indirectly monitored by the ARIMA model outcomes.

5. Conclusion

We have provided useful measurements of performance parameters of Thoroughbred horses based in the Southern Hemisphere. The results from this study showed a kinship significant effect over BW and WH. In addition to that, we developed a forecast model with maximum and minimum expected range values.

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6. References

_________. ABCPCC. Associação Brasileira de Criadores e Proprietários de Cavalos de Corrida (StudBook, Estatísticas Nacionais). Disponível em: <https://studbook.com.br/consultar-estatisticas#>. Acesso em: 20/1/2023.

_________. KER Gro-Trac Equine Growth Monitoring. . Kentucky: Kentucky Equine Research. Disponível em: <https://ker.com/tools/gro-trac/>. Acesso em 20/1/2023.

BARNEVELD, A.; VAN WEEREN, P. R. Conclusions regarding the influence of exercise on the development of the equine musculoskeletal system with special reference to osteochondrosis. Equine veterinary journal. Supplement, , n. 31, p. 112–119, 1999.

BELLAW, J. L.; PAGAN, J.; CADELL, S.; et al. Objective evaluation of two deworming regimens in young Thoroughbreds using parasitological and performance parameters. Veterinary Parasitology, v. 221, p. 69–75, 2016. Elsevier B.V. Disponível em: <http://dx.doi.org/10.1016/j.vetpar.2016.03.018>.

BELTRÁN, J. J.; BUTTS, W. T.; OLSON, T. A.; KOGER, M. Growth patterns of two lines of Angus cattle selected using predicted growth parameters. Journal of animal science, v. 70, n. 3, p. 734–741, 1992.

BROWN-DOUGLAS, C. G.; PAGAN, JOE D. Body Weight, Withers Height and Growth Rates in Thoroughbreds Raised in America, England, Australia, New Zealand and India. In: J D Pagan (Org.); Advances in Equine Nutrition IV. 4o ed, v. IV, p.213–220, 2009. Nottingham: Nottingham University Press.

BROWN-DOUGLAS, C. G.; PAGAN, JOE D.; STROMBERG, A. J. Thoroughbred growth and future racing performance. In: J. D. Pagan (Org.); Advances in Equine Nutrition IV. 1o ed, p.231–245, 2009. Nottingham: Nottingham University Press.

BROWN-DOUGLAS, C. G.; PARKINSON, T. J.; FIRTH, E. C.; FENNESSY, P. F. Bodyweights and growth rates of spring- and autumn-born thoroughbred horses raised on pasture. New Zealand Veterinary Journal, v. 53, n. 5, p. 326–331, 2005.

CANEVER, R. J.; BRAGA, P. R. C.; BOECKH, A.; et al. Lack of Cyathostomin sp. reduction after anthelmintic treatment in horses in Brazil. Veterinary Parasitology, v. 194, n. 1, p. 35–39, 2013. Elsevier B.V. Disponível em: <http://dx.doi.org/10.1016/j.vetpar.2012.12.020>.

CHRISTIE, J. L.; HEWSON, C. J.; RILEY, C. B.; et al. Management factors affecting stereotypes and body condition score in nonracing horses in Prince Edward Island. Canadian Veterinary Journal, v. 47, n. 2, p. 136–143, 2006.

COLPITTS, J.; MCLOUGHLIN, P. D.; POISSANT, J. Runs of homozygosity in Sable Island feral horses reveal the genomic consequences of inbreeding and divergence from domestic breeds. BMC Genomics, v. 23, n. 1, p. 1–17, 2022. BioMed Central. Disponível em: <https://doi.org/10.1186/s12864-022-08729-9>. .

CUNNINGHAM, K.; FOWLER, S. H. A study of growth and development in the quarter horse. LSA Agricultural Experiment Station Reports, v. 546, 1961. Disponível em: <http://digitalcommons.lsu.edu/agexp/636>. .

DIAS DE CASTRO, L. L.; ABRAHÃO, C. A. H.; ANTUNES, J.; PRITSCH, I.; MOLENTO, M. B. Body Development from Birth to 18 Months of Age of Thoroughbred Foals in Brazil. International Journal of Plant, Animal and Environmental Sciences, v. 11, n. 03, p. 352–362, 2021.

DINI, P.; KALBFLEISCH, T.; URIBE-SALAZAR, J. M.; et al. Parental bias in expression and interaction of genes in the equine placenta. Proceedings of the National Academy of Sciences of the United States of America, v. 118, n. 16, 2021.

ELLIOTT, C.; MORTON, J.; CHOPIN, J. Factors affecting foal birth weight in Thoroughbred horses. Theriogenology, v. 71, n. 4, p. 683–689, 2009.

FARIA, R.; SILVA, M. DE A. E; BUENO, R. S.; et al. Avaliação genética e fenotípica de características de conformação em potros de três raças equinas. Revista Ceres, v. 51, n. 295, p. 333–344, 2004.

FITZHUGH JR., H. A. Analysis of growth curves and strategies for altering their shape. Journal of Animal Science, v. 42, n. 4, p. 1036–1051, 1976.

FRADINHO, M. J.; BESSA, R. J. B.; FERREIRA-DIAS, G.; CALDEIRA, R. M. Growth and development of the Lusitano horse managed on grazing systems. Livestock Science, v. 186, p. 22–28, 2016. Elsevier. Disponível em: <http://dx.doi.org/10.1016/j.livsci.2015.06.006>. .

GARCIA, F. P. S.; ALFAYA, H.; LINS, L. A.; VELHO, J. R.; NOGUEIRA, C. E. W. Influence of the maternal age and number of labors in the performance of Thoroughbred horses raised in Bagé, southern Brazil. Revista Por, v. 110, n. 577–580, p. 39–42, 2011.

GIANOLA, D.; WEIGEL, K. A.; KRÄMER, N.; STELLA, A.; SCHÖN, C. C. Enhancing genome-enabled prediction by bagging genomic BLUP. PLoS ONE, v. 9, n. 4, 2014.

HILL, E. W.; STOFFEL, M. A.; MCGIVNEY, B. A.; MACHUGH, D. E.; PEMBERTON, J. M. Inbreeding depression and the probability of racing in the Thoroughbred horse. Proceedings of the Royal Society B: Biological Sciences, v. 289, n. 1977, p. 1–7, 2022.

HINTZ, R. L.; HINTZ, H. F.; VAN VLECK, L. D. Estimation of heritabilities for weight, height, and front cannon bone circumference of Thoroughbreds. Journal of Animal Science, v. 47, n. 6, p. 1243–1245, 1978.

HUNTINGTON, P. J.; BROWN-DOUGLAS, C. G.; PAGAN, J. D. Growth and development of Thoroughbred horses. Animal Production Science, v. 60, n. 18, p. 2093–2102, 2020.

JELAN, Z. A.; JEFFCOTT, L. B.; LUNDEHEIM, N.; OSBORNE, M. Growth rates in thoroughbred foals. Pferdeheilkunde, v. 12, n. 3, p. 291–295, 1996.

KAVAZIS, A. N.; OTT, E. A. Growth rates in Thoroughbred horses raised in Florida. Journal of Equine Veterinary Science, v. 23, n. 8, p. 353–357, 2003.

KLEWITZ, J.; STRUEBING, C.; ROHN, K.; et al. Effects of age, parity, and pregnancy abnormalities on foal birth weight and uterine blood flow in the mare. Theriogenology, v. 83, n. 4, p. 721–729, 2015. Elsevier Inc. Disponível em: <http://dx.doi.org/10.1016/j.theriogenology.2014.11.007>.

KOCHER, A.; STANIAR, W. B. The pattern of Thoroughbred growth is affected by a foal's birthdate. Livestock Science, v. 154, n. 1–3, p. 204–214, 2013. Elsevier. Disponível em: <http://dx.doi.org/10.1016/j.livsci.2013.03.008>.

KUHI, H. D.; HOSSEIN-ZADEH, N. G.; FRANCE, J.; LÓPEZ, S. The description of equine somatic growth using nonlinear functions. Journal of Equine Veterinary Science, v. 111, p. 103893, 2022. Elsevier Inc. Disponível em: <https://doi.org/10.1016/j.jevs.2022.103893>.

LEACH, D.; CYMBALUK, N. F. Relationships between stride length, stride frequency, velocity, and morphometrics of foals. American journal of veterinary research, v. 47, n. 9, p. 2090–2097, 1986. Disponível em: <https://archive.org/details/sim_american-journal-of-veterinary-research_1986-09_47_9/page/2090/mode/2up>. .

MANSO FILHO, H. C.; HUNKA, M. M.; WANDERLEY, E. K.; et al. Pattern of Development in Foals from Four Different Breeds between Birth and Weaning. Open Journal of Veterinary Medicine, v. 04, n. 05, p. 72–77, 2014.

MATTHEE, S.; KRECEK, R. C.; MILNE, S. A.; BOSHOFF, M.; GUTHRIE, A. J. Impact of management interventions on helminth levels, and body and blood measurements in working donkeys in South Africa. Veterinary Parasitology, v. 107, n. 1–2, p. 103–113, 2002.

MCGIVNEY, B. A.; HAN, H.; CORDUFF, L. R.; et al. Genomic inbreeding trends, influential sire lines and selection in the global Thoroughbred horse population. Scientific Reports, v. 10, n. 1, p. 1–12, 2020.

MOLENTO, M. B. Resistência parasitária em helmintos de equídeos e propostas de manejo. Ciência Rural, v. 35, n. 6, p. 1469–1477, 2005. Disponível em: <https://doi.org/10.1016/j.vetpar.2017.12.012>. .

MOLENTO, M. B.; VILELA, V. L. R. Health evaluation of donkeys: Parasite control methods and a model for challenge infections. Brazilian Journal of Veterinary Research and Animal Science, v. 58, n. Special Issue, 2021.

MOREL, P. C. H.; BOKOR, Á.; ROGERS, C. W.; FIRTH, E. C. Growth curves from birth to weaning for thoroughbred foals raised on pasture. New Zealand Veterinary Journal, v. 55, n. 6, p. 319–325, 2007.

ONODA, T.; YAMAMOTO, R.; SAWAMURA, K.; et al. Empirical growth curve estimation considering multiple seasonal compensatory growths of body weights in Japanese Thoroughbred colts and fillies. Journal of Animal Science, v. 91, n. 12, p. 5599–5604, 2013.

PAGAN, J. D. Managing growth for different commercial end points. In: J. D. Pagan (Org.); Advances in Equine Nutrition III. 1o ed, p.319–326, 2005. Nottingham: Nottingham University Press.

PAGAN, J. D.; BROWN-DOUGLAS, C. G.; CADDEL, S. Body weight and condition of Kentucky Thoroughbred mares and their foals as influenced by month of foaling, season and gender. In: J. D. Pagan (Org.); Advances in Equine Nutrition IV2. 1o ed, p.137–145, 2009. Nottingham: Nottingham University Press.

PAGAN, J. D.; JACKSON, S. G. The incidence of developmental orthopedic disease on a Kentucky thoroughbred farm. Pferdeheilkunde, v. 12, n. 3, p. 351–354, 1996.

PAGAN, J. D.; JACKSON, S. G.; CADDEL, S. A summary of growth rates of Thoroughbreds in Kentucky. Pferdeheilkunde, v. 12, n. 3, p. 285–289, 1996.

REINEMEYER, C. R.; FARLEY, A.; CLYMER, B. Comparisons of cyathostome control and selection for benzimidazole resistance using larvicidal regimens of moxidectin gel or fenbendazole paste. International Journal of Applied Research in Veterinary Medicine, v. 1, n. 1, p. 66–72, 2003. Disponível em: <http://www.jarvm.com/articles/Vol1Iss1/REINMJVM.htm>. .

SAASTAMOINEN, M. Heritabilities for Body Size and Growth Rate and Phenotypic Correlations Among Measurements in Young Horses. Acta Agriculturae Scandinavica, v. 40, n. 4, p. 377–386, 1990.

SANTANA, B.F., MAMANI, G.C., OLIVEIRA, G.A. DIAS DE CASTRO, L.L., MOLENTO, M. B., VENTURA, R.V., FERRAZ, J.B.S. Characterization of runs of homozygosity in a population of Thoroughbred horses. Ciência & Tecnologia, v.9, n.1, p. 1-6, 2017.

SAVAGE, C. J.; MCCARTHY, R. N.; JEFFCOTT, L. B. Effects of dietary energy and protein on induction of dyschondroplasia in foals. Equine Veterinary Journal, v. 25, n. 16 S, p. 74–79, 1993.

SCHRODERUS, E.; OJALA, M. Estimates of genetic parameters for conformation measures and scores in Finnhorse and Standardbred foals. Journal of Animal Breeding and Genetics, v. 127, n. 5, p. 395–403, 2010.

SCHRURS, C.; BLOTT, S.; DUBOIS, G.; VAN ERCK-WESTERGREN, E.; GARDNER, D. S. Locomotory Profiles in Thoroughbreds: Peak Stride Length and Frequency in Training and Association with Race Outcomes. Animals, v. 12, n. 23, 2022.

SILVA, R. H. P.; REZENDE, A. S. C.; SALIBA, E. DE O. S.; et al. The effect of deworming on apparent digestion, body weight, and condition in heavily parasitized mares. Journal of Equine Veterinary Science, v. 36, p. 83–89, 2016. Elsevier Ltd. Disponível em: <http://dx.doi.org/10.1016/j.jevs.2015.10.001>. .

SMITH, A. M.; STANIAR, W. B.; SPLAN, R. K. Associations between yearling body measurements and career racing performance in Thoroughbred racehorses. Journal of Equine Veterinary Science, v. 26, n. 5, p. 212–214, 2006.

STANIAR, W. B.; KRONFELD, D. S.; TREIBER, K. H.; SPLAN, R. K.; HARRIS, P. A. Growth rate consists of baseline and systematic deviation components in Thoroughbreds. Journal of Animal Science, v. 82, n. 4, p. 1007–1015, 2004.

TEIXEIRA, G. L.; FERNANDES, T. J.; MUNIZ, J. A.; et al. Growth curves of campolina horses using nonlinear models. Livestock Science, v. 251, n. September 2020, 2021. Elsevier B.V.

WOLF, J. B.; HAGER, R. A maternal-offspring coadaptation theory for the evolution of genomic imprinting. PLoS Biology, v. 4, n. 12, p. 2238–2243, 2006.