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Genetic and quantitative evaluation of breeding traits in thoroughbred mares

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Summary

Very little information is found about genetic parameters of breeding traits in horses. Therefore, a study was conducted utilizing information from 7,278 Thoroughbred mares, of which there were 6,327 entries regarding age at first covering (AFC), 5,400 related to age at first parturition (AFP), 5,473 related to first period of gestation (FPG) and 4,404 related to first foaling interval (FFI). Data were analyzed using maximum restricted likelihood, with the application of MTDFREML ("Multiple Trait Derivative Free Restricted Maximum Likelihood; Boldman et al., 1993) for variance and covariance components estimate. The average age at first covering was 4.93 years, with a standard deviation of 1.45 years, minimum of 2.07 and maximum of 11.94 years. The components of additive (σ^2_a), environmental (σ^2_e), phenotypic (σ^2_p) variances and heritability (h^2) were 0.34048, 1.42908, 1.76955 and 0.19 respectively. Average age at first parturition was 6.01 years, with a standard deviation of 1.53 years, minimum of 3.01 and maximum of 12.9 years. The components of additive (σ^2_a), environmental (σ^2_e), phenotypic (σ^2_p) variances and heritability (h^2) found were 0.84324, 1.39398, 2.23722 and 0.38, respectively. The average of first period of gestation was 337.83 days, with a standard deviation of 9.47 days, minimum of 302 and maximum of 396 days. The components of additive (σ^2_a), environmental (σ^2_e), phenotypic (σ^2_p) variances and heritability (h^2) were 13.01471, 66.34142, 79.35613 and 0.16, respectively. The average of first foaling interval was 490.18 days, with a standard deviation of 192.02 days, minimum of 303 e maximum of 1095 days. The components of additive (σ^2_a), environmental (σ^2_e), phenotypic (σ^2_p) variances and heritability (h^2) found were 351.88679, 34836.79221, 35188.679 and 0.01, respectively.

Keywords: Equine, Reproduction, Genetic parameters

Introduction

It is estimated that the use of horses directly employs more than 600 thousand people in Brazil and involved around 3.1 billion dollars per year (Lima et al., 2006) constituting an important chain in the national agribusiness, strongly correlated with leisure, culture, sport and tourism (Guerra, 2003).

The Thoroughbred breed, whose starting records date back to the 1700s, were formed with the import of animals from the East and stallions of the Arabian, Berber and Turkish breeds, which were mated with mares native to England and Andalusian females, aiming at producing race-suitable horses (Bowling and Clark, 1985).

Differently from other domestic species, equines were selected in remote times due to their performance in equestrian sports; and owing to that fact no satisfactory attention was placed to their fertility traits (Phillips, 1977).

Horses have been adapting for millions of years in order to create a model of breeding which ensures their survival in nature. However, domestication has exerted a strong influence on their bred performances, amounting to little, or no pressure on fertility by selection. More importantly, it is a horse’s performance that determines the mating (Reproductive, 2004).

For that reason, equines show a low reproductive performance when compared to other species within the range of interest of animal science. This low fertility may be related to hormonal dysfunction, several genital infections in mares and wrong handling techniques in mares before natural covering season, showing limiting factors to a better reproductive performance of this specie (Sullivan et al, 1975).

The above mentioned factors are more predominant in breeds used in sports, since they have a differentiated handling from those used only for breeding (Jackson, 1971).

Considering that the success of the Thoroughbred industry is measured by racing performances, it is understandable that intense efforts are being made daily in that industry to maximize the individual performance of horses in tests (More, 1999). However, it must be said that no or little knowledge about reproductive indices of results in lower selective intensity, reflecting on lower genetic gains in the population, which, in last instance, may affect a horse’s racing performance.

For that matter, the goal of this study was to estimate genetic parameters for reproductive traits in thoroughbred mares in order to provide scientific basis for national selection programs that aim at improving them.

Material and Methods

The data used in this study were given by the “Associação Brasileira dos Criadores do Cavalo de Corrida” (ABCCC), and can be found in the files “Pedigree” and “Performance” of the CD-ROM developed by that Association in 1999. Information on 7,278 Thoroughbred mares, born between 1967 and 1994, was analyzed, of which 6,327 entries relate to age at first covering (AFC), 5,400 relate to age at first parturition (AFP), 5,473 relate to first period of gestation (FPG) and 4,404 relate to first foaling interval (FFI). There were 27,217 animals in the relationship matrix.

Conception and apparent fertility rates were calculated as the total number of mares that becomes pregnant divided by the total number of mating mares and the number of mares that bore live foals divided by the number of mating mares, respectively (Hugason et al., 1985).

The data files containing information on reproductive traits underwent critical analysis (descriptive statistics; frequencies, means, deviations, amplitudes, etc.) using "SAS" (Statistical Analysis System), version 6.04 (Sas Institute Inc., 1999). This analysis aimed at providing information for the elimination of records that were shown to be inconsistent, seeking to improve data reliability and consistency. Also in this phase were taken the groups of contemporaries, observing the factors that significantly influenced the studied traits.

The variance components necessary to obtain the heritability of the studied traits were estimated using the Method of Derivative Free Restricted Maximum Likelihood, on animal model, in unicharacter analysis, from MTDFREML (Boldman et al., 1993). Later, in order to estimate genetic and phenotypic correlations between them, bicharacter analyses were used. In this case, the strategy used to estimate covariances followed the one described by Boldman et al. (1993).

Contrast tests were conducted for class comparisons involving the effects of sex and stallion's origin. In these tests, in case the value for contrast was twice as big as its standard error, it was considered significant at 5% (Boldman et al., 1993).

The model of analysis used may be represented by:

$$Y = X\beta + Za + \varepsilon$$

where::

y = is the vector of the observations; X = is the matrix of incidence of fixed effects; β = is the vector of fixed effects; Z = is the matrix of incidence of direct genetic effects; a = is the vector of direct genetic effects; ε = is the vector of random errors associated with the observations.

Age at First Covering

It included besides the animal's random effect, the fixed effects of breeder (1,036) and contemporary group (169) formed by mares born in the same year (1967 to 1994) and period (1-July; 2-August; 3-September; 4-October; 5-November; 6-December; 7-January to June), and having at least three animals each.

Age at First Parturition

It included besides the animal's random effect, the fixed effects of breeder (1,036), product's sex (male and female), origin of stallion (national and imported) and contemporary group (143), formed considering foaling occurred in the same year (1972 to 1999) and period (as described above), and having at least 3 animals each.

First Foaling Interval

It included the besides animal's random effect, the fixed effects of breeder (1,036), product's sex (male and female) and contemporary group (134), formed by mares foaling in the same year (1972 to 1999) and period (as described above), and having at least 3 animals each.

First Period of Gestation

The real period of gestation should be calculated starting on ovulation day (fertilization) and ending on foaling day. However, the first date cannot be accurately determined without the help of ultrasound or rectum palpation. Therefore, the date of the last mating is used to calculate the length of gestation (Hura et al., 1994), as conducted in this study.

It included, besides an animal's random effect, fixed effects of breeder (1,036), product's sex (male and female), origin of stallion (national and imported) and contemporary group (147) formed by mares that foaled in the same year-period.

Results

Coverings

42,750 mating from 7,278 Thoroughbred mares were evaluated and their occurrences are shown in Table 1. It was observed that birthrates for males and females were 49.26% and 50.74%, respectively, whereas for miscarriages and stillborn foals, 1.41% and 2.02%, respectively. It was also recorded that 9.07% of coverings were classified as empty, whereas 23.07% of mating did not show later records.

Table 1.Occurrences after mating

Occurrence	Number of observations and (%)
Male	12,550 (29.35%)
Female	12,927 (30.23%)
Miscarriages	603 (1.41%)
Empty	3,878 (9.07%)
Without information	9,864 (23.07%)
Stillborn	866 (2.02%)
Not mated	1,945 (4.54%)
Mated with another breed	135 (0.31%)

Stallion

It was observed that, of the 3,083 stallions used in covering, 2,237 animals (72.6%) were national, and 846 (27.4%) were imported. National stallions did 21,449 (50.18%) coverings, whereas imported ones were responsible for 18,408 (43.06%) coverings, totaling together 39,857 coverings, whereas for 2,893 (6.76%) coverings there was no information on origin of the stallion used.

A birthrate of males and females was recorded at 48.78%, 51.22% and 49.70%, 50.3% for national and imported stallions, respectively. Miscarriage and stillborn rates were quite close, at 1.62% and 1.26% for the former and 2.30% and 1.92% for the latter, considering Brazilian and foreign stallions, respectively. As regards coverings with no records, 29.59% were found to be related to national animals, decreasing to 18.07% when analyzing imported animals.

Regarding national stallions, 56.32% of coverings done by those animals resulted in live foals, up to 70.82% for foreign animals. National stallions showed an average of 5.4 offspring, whereas the imported ones had 15.4 offspring.

The occurrences after coverings in national and imported animals are found in Table 2.
Conception and apparent fertility rates

Table 2. Occurrences after coverings in national and imported stallions

Occurrence	National	Imported
Male	5,893 (27.47%)	6,480 (35.20%)

Female	6,188 (28.85%)	6,557 (35.62%)
Miscarriages	347 (1.62%)	232 (1.26%)
Empty	2,176 (10.14%)	1,442 (7.84%)
Without information	6,328 (29.59%)	3,327 (18.07%)
Stillborn	493 (2.30%)	354 (1.92%)
Not mated	24 (0.11%)	15 (0.08%)
Mated with another breed	0 (0%)	1 (0.005%)

Conception and apparent fertility rates found were 66% and 63%, respectively, and are shown in Table 3.

Table 3. Conception and apparent fertility rates according to parturition order of mares

Parturition order	Conception rate (%)	Apparent Fertility Rate (%
1	75	71
2	73	68
3	71	68
4	69	67
5	67	65
6	64	61
7	62	59
8	59	56
9	56	54
10	54	52
11	48	47
12	48	46
> 13	41	38

Age at First Covering

The average age at first covering (AFC) was 4.93 years, with a standard deviation of 1.45 years, minimum of 2.07 and maximum of 11.94 years (Table 4). The components of additive (σ^2_a), environmental (σ^2_e), phenotypic (σ^2_p) variances, and heritability (h^2) found were 0.34048, 1.42908, 1.76955 and 0.19, respectively (Table 5).

Age at First Foaling

The average age at first foaling (AFF) was 6.01 years, with a standard deviation of 1.53 years, minimum of 3.01 and maximum of 12.9 years (Table 4). The components of additive (σ^2_a), environmental (σ^2_e), phenotypic (σ^2_p) variance and heritability (h^2) found were 0.84324, 1.39398, 2.23722 and 0.38, respectively (Table 5).

First Period Gestation

The average of first period of gestation (FPG) was 337.83 days, with a standard deviation of 9.47 days, minimum of 302 and maximum of 396 days (Table 4). The components of additive (σ^2_a), environmental (σ^2_e) and phenotypic (σ^2_p) variances and heritability (h^2) found were 13.01471, 66.34142, 79.35613 and 0.16, respectively (Table 5).

First Foaling Interval

The average of first foaling interval (FFI) was 490.18 days, with a standard deviation of 192.02 days, minimum of 303 and maximum of 1095 days (Table 4). The components of additive (σ^2_a), environmental (σ^2_e), phenotypic (σ^2_p) variance and heritability (h^2) found were 351.88679, 34836.79221, 35188.679 and 0.01, respectively (Table 5).

Table 4. Number of observations (N), general mean, coefficient of variation (CV) and maximum and minimum values of the studied traits

Trait	N	Mean	CV (%)	Maximum	Minimum
AFC (years)	6.327	4.93	29.59	2.07	11.94
AFF (years)	5.400	6.01	25.19	3.01	12.9
FPG (days)	5.473	337.83	29.44	302	396
FFI (days)	4.404	490. 18	39.17	303	1095

Table 5. Components of additive (σ^2_a), phenotypic (σ^2_p), environmental (σ^2_e) variances and heritability (h^2) for age at first covering, age at first foaling, first period of gestation and first foaling interval.

Trait	σ^2_a	σ^2_e	σ^2_p	h^2
AFC	0.34048	1.42908	1.76955	0.19 (0.035
AFF	0.84324	1.39398	2.23722	0.38 (0.043
FPG	13.01471	66.34142	79.35613	0.16 (0.035
FFI	351.88679	34836.7922:	35188.679	0.01 (0.029

( ) standard error.

Genetic and phenotypic correlations between the evaluated traits, as well as the analysis of estimates of heritability in bicharacter analysis are shown in Table 6.

Table 6. Genetic parameters for age at first foaling, age at first covering, first foaling interval and first period of gestation

Trait	AFF	AFC	FFI	FPG
AFF	0.27	1	0.52	0.35
AFC	0.88	0.12	0.55	- 0.13
FFI	0.02	0.02	0.01	- 0.54
FPG	0.06	- 0.03	- 0.004	0.16

Above diagonal = genetic correlation
Main diagonal = heritability
Below diagonal = phenotypic correlation

Fixed effects for sex were significant (P< 0,05) for the first period of gestation and first foaling interval, whereas the origin of stallion was significant (P< 0,05) for the first period of gestation.

Discussion

Coverings

Of the 42,750 mating studied, the births of 12,550 males (49.26%) and 12,927 females (5074%) were recorded, amounting to a total difference in sexes of 1.48%, considerably lower than the 10% found by Davies Morel et al. (2002), who recorded a percentage of male births of 45% and female births of 55% in Thoroughbred horses.

Regarding miscarriages, defined as the expulsion of the fetus before 300 days of gestation (Reproductive, 2004), a rate of 1.41% was observed, a value that is lower than the 4.6%, 7.0% and 9% recorded by Jeffcott et al. (1982), Merkt et al. (2000) and Klemetsdal et al. (1989) in thoroughbred mares, respectively**.** 2.02% was found as the rate of stillborn, a value close to the ones observed by Jeffcott et al. (1982) and lower than the 7.1% observed by Laing and Leech (1975) in Thoroughbred horses.

It was recorded that 23.07% of the coverings that occurred did not have recorded results, which demonstrates, in part, a certain organizational inefficiency in breed. Furthermore, this value may have underestimated birth, miscarriage and stillborn rates found in this study.

Conception and Apparent Fertility Rate

The average conception rate was 66%, whereas apparent fertility lay at 63%. These values are lower than the 82.5% and 81.06% recorded by Hugason et al. (1985) for conception and apparent fertility rates in Thoroughbred mares, respectively. The apparent fertility rate is also lower than the 71% found by Davies Morel and Gunnarsson (2000), who consider fertility rate as the apparent fertility rate propounded by Hugason et al. (1985). These results may express, in part, the difficulty in estimating some of the fertility parameters. Moreover, gestation diagnoses not performed in the early months after a covering may classify mares that had miscarriages as not conceived.

These rates (conception and apparent fertility), according to foaling order of mares, are displayed in Table 3. It can be observed that, as mare foaling order increases, the value for both taxes decreases. These results are in agreement with literature, which records lower fertility rates for aged mares, owing to ovarian failures, ovum's reduced viability, uterine degeneration and higher incidence of infections in the reproductive trait (Carnevale et al., 1993; Schideler, 1993).

Age at First Covering

The average age at first covering was 4.93 years, with a standard deviation of 1.45 years, minimum of 2.07 and maximum of 11.94 years. This average is slightly higher than the 4.25 and 4.33 years reported by Singh et al. (2002) for the Indian breeds Marwari and Kathiawari.

The variance components estimate analysis (Table 5) stressed the little importance of additive genetic components and non-genetic additive components, which represents about 80% of phenotypic variance. Indeed, this trait is highly dependent of environmental factors, stressing breeder's intention as to when to initiate animals' reproductive life, influenced by nutritional and sanitary factors as well as the management of each farm.

Genetic correlation of AFC and AFF was 1, indicating that the same genes act in both traits, and selection applied to only one of them would be necessary. Phenotypically, these traits are also shown to be positively and highly correlated, indicating that lower ages at first covering are associated with earlier age at first foaling. These results were expected since there is a high dependency of AFF regarding AFC.

With regards to the genetic correlation between AFC and FFI, a positive moderate-magnitude (0.55) estimate was observed, indicating that selections for ages at first earlier coverings could cause favorable genetic alterations (diminution) on the FFI. On the other hand, these traits showed phenotypically independent, indicating that earlier (or later) ages at first covering are not related to lower (or higher) first foaling interval.

The correlations of AFC with FPG were both negative and low magnitude. With regards to genetics (- 0.13), it is observed that selection aimed at lowering age at first covering practically would not cause considerable increases on FPG, owing to the low heritability of this trait. Phenotypically, the relationship between them was rather weak (- 0.03), showing that earlier or later ages at first covering are not related with a shorter or longer FPG.

With the aforementioned in mind, the low heritability estimate magnitude found (0.12) indicates that this trait is little influenced by genes of an additive action, suggesting that mare selection based on age at first covering would not lead to rapid genetic changes in the population, and information from collateral relatives and offspring should be incorporated to improve the identification of genetically superior animals.

Age at First Parturition

The average age at first parturition was 6.01 years, with a standard deviation of 1.53 years, minimum of 3.01 and maximum of 12.9 years. This result is lower than the 6.89 and 6.34 years, recorded by Valera et al. (2000) and Fuentes et al. (1990) for Lusitano and Arabian equines, respectively. Even higher values were found by Langlois (1976), for Thoroughbred horses aged 8 at first parturition. However, Pares (1995) observed age at first parturition between 4 and 5 in Ceretano Bretão horses, which can be justified by these animals not being normally used in equestrian activities.

The heritability estimate found was an average magnitude (0.27), indicating moderate relationship intensity between genetic and phenotypic values for this trait. However, compared to the other studied traits, it showed a higher heritability estimate, suggesting some possibility of genetic gain through selection. Furthermore, it showed the advantage of being observed relatively early in a mare's life.

Positive and moderate estimate of genetic correlation (0.52) between AFF and FFI indicates that selection for lower ages at first parturition would cause favorable changes in the correlated trait, decreasing the time at second parturition. On the other hand, when the value of phenotypic correlation is observed (0.02), it is noted that these traits are independent, i.e., earlier or later ages at first foaling are not associated with first foaling interval of lower or higher parturitions.

The genetic correlation of AFF with FPG was 0.35, indicating the low tendency of animals with genetic values associated with a later (or earlier) AFF to be related to longer (or shorter) genetic values for FPG. On the other hand, phenotypically, the correlation between both of them was close to zero (0.06), showing independency between them.

Considering the correlations and genetic variances found in the present study, it was seen that selection for AFF would promote genetic gains correlated with AFC and FFI higher than those obtained by direct selection in the last traits, allowing of equal selective intensity and foaling intervals.

Age at first foaling is further considered to be an important trait in a mare's reproductive performance evaluation process, with results in the whole system of horse breeding.

First Period of Gestation

The first average period of gestation was 337.83 days, with a standard deviation of 9.47 days, minimum of 302 and maximum of 396 days. These values are the 300 to 400 days' variation, with average close to 340 days described by Marteniuk et al. (1998), for the equine species. It must be said, however, that values lower than 300 days were found by Vassilev et al. (2002), 291 days, and Hura et al. (2002), 297 days and gestations higher than 400 days were reported by Pribyl (1952), quoted by Durutty (1993), 412 days, and Hula et al. (2002), 414 days.

The average for that trait found in this study is higher than the 327 days reported by Zúccari et al. (2002) for Pantaneira mares and lower than the 344.1 days, recorded by Davies Morel (2002) for Thoroughbred mares. However, Haudi (1966), Valência and Gonzales (1976) and Arora (1983) found approximate results for Thoroughbred, Indian, Mexican, and Australian mares (334, 335 and 335 days), respectively.

The product's sex and the origin of stallion significantly influenced gestation length. Most studies report longer gestations for male sex fetuses, Uppenborn, (1993), Mauch (1937), Rossdale et al. (1967), Hura et al. (1997), Marteniuk et al. (1998); the same occurred in this study, which recorded statistical differences ($P < 0.05$) of an extra 1.9 days for male gestations, corroborating the results shown by Davies Morel et al. (2002), who recorded an extra 3.8 days for male gestations for Thoroughbred horses. Although it is usually accepted that males, in several species, have longer gestations than females, the reason is not clear (Jainudeen and Hafez, 2000). It is postulated, however, that the difference is due to different endocrinal functions in male and female fetuses, interacting in a different manner with the endocrinal control of parturition (Jainudeen and Hafez, 2000).

As regards stallion's origin, a significant difference (P < 0.05) between national and imported animals was observed, in which the former had an extra 1.2 days for gestation length comparing to the latter. Considering that breeders aim at obtaining products born at the beginning of race year in order to use their competitive advantage compared to animals born later in the same race year (Cunningham, 1991), stallions associated with longer gestation lengths may be desirable to breed with females at the end of the season (Marteniuk et al., 1998).

The estimated heritability for this trait (0.16) is lower than the 0.30 reported by Vassilev et al. (2002) and close to 0.19 found by Borges (1973), for Mangalarga breed, indicating that this trait is little influenced by additive action genes and that mare selection based on period of gestation would not lead to rapid genetic changes in the population.

The low magnitude of the phenotypic correlation between FPG and FFI (- 0.004) demonstrate that these two traits are independent, i.e**.,** gestation length of mares is not associated with lower or higher foaling intervals. Considering the value for genetic correlation between them (- 0.54), albeit negative and mean magnitude, selection for first period of gestation would not cause an impact on foaling interval, due to the low value of its heritability (0.01).

First Foaling Interval

The first average foaling interval found was 490.18 days, with a standard deviation of 192.02 days, minimum of 303 and maximum of 1,095 days. This mean is higher than the 468 days' foaling interval of Hafling mares, reported by Meregali and Valzania (1984). However, it is lower than the 535 and 567 days recorded by Singh et al. (2002) for the indian Marwari and Kathiawari breeds**.**

There was a significant effect (P < 0.05) of the product's sex on this trait, indicating that the gestation of colts culminated in an extra 13.49 days in the first foaling interval, which can be justified, in part, by the male gestation length found in this study.

The low heritability estimate found for this trait (0.01) demonstrates the great environmental influence to which this trait is subject, suggesting that phenotypic values do not show a great correlation with genetic values, making the determination of which animals are genetically superior as well as response to selection is more difficult. Moreover, the incorporation of this trait in genetic improvement programs would result in little response to selection, demanding that stallions have a great number of fillies evaluated so that genetic values may offer sufficient reliability.

In broad terms, traits related to reproduction, such as, are highly influenced by environmental and non additive genetic factors. Thus, more rapid gains in this trait may be achieved by improving management, sanitation, and nutrition conditions and reproductive control of the flock.

High first foaling intervals, as found in this study, culminate in last analysis in a lower selective intensity, resulting in lower genetic gains in the population and making genetic improvement work more difficult.

Conclusion

Among the evaluated traits, AFF was shown to be more prone to be incorporated by selection programs that aim at improving reproductive aspects of Thoroughbred horses in Brazil, not only because of its higher heritability estimate, but also because it is genetically correlated with the other traits in a favorable manner.

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