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REVIEW

Predictors of foaling outcomes in barren and maiden Thoroughbred mares in South Africa

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Population demographics and reproductive performance of Thoroughbred populations have been described, but the most recent assessment of the South African Thoroughbred population was reported two decades ago.

Objectives of this study were to report demographic data for selected Thoroughbred breeding populations and to analyse selected mare-level variables in association with foaling outcomes, as predictors of reproductive performance.

The National Horseracing Authority of Southern Africa's stud health scheme requires annual screening of Thoroughbred stallions, maiden and barren mares for venereal pathogens prior to breeding. In 2018 and 2019, 1 065 and 1 207 horses were sampled, respectively. Demographic data were sourced from laboratory sample submission forms that accompanied samples and supplemented by data gathered from the annual Thoroughbred foal identification programme. Univariate analysis of candidate predictors of successful foaling outcomes was performed followed by assessment in a multivariable model.

Median ages of mares and stallions tested in 2018 and 2019 were nine and 11 years, respectively. Nearly twice the number of barren compared to maiden mares were tested in each year, and failure to conceive was the most common reported reason for classification as barren. Of mares tested in 2018 and 2019, 68.1% (95% CI 65.1–70.9) and 63.3% (95% CI 60.4–66.1), respectively, subsequently produced foals that were presented for identification. Mare age, rather than reproductive status, was a significant predictor of having a foal presented for identification.

In conclusion, novel demographic data were described for South African Thoroughbred populations. Seasonal foaling rate as the selected measure of reproductive performance for sampled mares ranged from 63.3% to 68.1% and declined with increasing mare age.

Keywords: horse, Thoroughbred, reproduction, maiden, barren, mare, foaling outcomes, predictors

Introduction

Studies from countries including Australia, New Zealand, the United Kingdom (UK), United States of America (USA) and Sweden have reported demographic or reproductive performance data for Thoroughbred breeding populations (Allen et al. 2007; Bosh et al. 2009; Hanlon et al. 2012; Hemberg et al. 2004; Nath et al. 2010; Roach et al. 2021). The association of age, reproductive status and parity with foaling outcomes have been described, with reproductive performance decreasing with increased mare age (Bosh et al. 2009; Chevalier-Clément 1989; De Mestre et al. 2019; Hanlon et al. 2012; Hemberg et al. 2004; Hutton & Meacham 1968; Jeffcott et al. 1982; Lane et al. 2016; McDowell et al. 1992; Rose et al. 2018; Schulman et al. 2013; Waelchli 1990) whereas conflicting results have been reported for both mare reproductive status (Allen et al. 2007; Blanchard et al. 2010; Brück et al. 1993; De Mestre et al. 2019; Hanlon et al. 2012; Lane et al. 2016; Miyakoshi et al. 2012; Morris & Allen 2002; Nath et al. 2010; Riddle et al. 2007; Woods et al. 1987) and parity (Allen 1993; Chevalier-Clément 1989; De Mestre et al. 2019; Ricketts & Alonso 1991; Yang & Cho 2007). The most recent assessment of South African Thoroughbred reproductive performance reported a live foal rate of 62% for the 1999 breeding season (Schulman et al. 2003).

The National Horseracing Authority (NHA) of Southern Africa's stud health scheme (SHS) requires annual testing of all Thoroughbred stallions, maiden and barren mares to screen for bacterial venereal disease. Foaling mares were historically not sampled as they were considered in a lower risk category for venereal disease. In addition, these mares were pregnant during the initial phase of the covering season, which precluded the endometrial sampling required by the SHS prior to 2018. Laboratory sample submission forms accompanying samples from stallions and maiden and barren mares and submitted by veterinarians provide a vehicle for the collection of demographic data from this population. Historically, SHS data collection, collation and reporting were incomplete and thus accurate data were not available to monitor or at least estimate, population demographics and reproductive performance of South African Thoroughbreds (Schulman et al. 2003). Additionally, breeder reported coverings and live foal rates are under-reported and thus not available to determine reproductive performance of South African Thoroughbreds.

The objective of this study was to collate and report data derived from laboratory sample submission forms over two successive breeding seasons to provide novel demographic information and, in conjunction with data derived from the national Thoroughbred foal identification programme, to estimate the per season foaling rate as a measure of reproductive performance (Bosh et al. 2009) of South African Thoroughbred maiden and barren mares. A further objective was to analyse selected mare-level data, including mare age, reproductive status, parity, and geographic location, in association with foaling outcomes of the South African Thoroughbred maiden and barren mare population.

Materials and methods

Population demographics and reproductive outcomes

Genital swabs obtained from Thoroughbred stallions (n = 75 and 77 in 2018 and 2019, respectively) and maiden and barren mares, collectively referred to as sampled mares, (n = 990 and 1 130 in 2018 and 2019, respectively) during two consecutive southern hemisphere breeding seasons were collected and submitted by veterinarians. All samples were submitted to the Equine Research Centre (ERC) of the University of Pretoria in South Africa for testing in compliance with the NHA's SHS. Population demographics were derived from information sourced from sample submission forms (which accompanied genital swab samples) and supplemented by data obtained from the UPEquID Access® database (Microsoft® Corporation, Redmond, Washington, USA) held by the NHA and ERC, which included data gathered from the annual Thoroughbred foal identification programme for approximately 20 years.

The ages of both stallions and mares were categorised as ≤ 5, 6–10, 11–15 and ≥ 16 years. In addition, for mares, their reproductive status categorisation (maiden or barren), reason for allocation as a barren mare, parity, and foaling outcomes for the 2018 and 2019 breeding seasons were reported. The number of mares reported as maiden or barren on sample submission forms was corrected post hoc according to database records. Mares were classified as 'unspecified' when available information did not allow the determination as maiden or barren. Maiden mares were defined as mares that had not previously been bred (Hanlon et al. 2012). Barren mares were defined according to the SHS as mares that had previously been bred but had not produced a live foal in the current season (Anonymous 2020). Reasons for barren status of mares were supplied by breeders on sample submission forms. Mare parity was categorised as 0–2, 3–5, 6–8, 9–11, 12–14, 15–17 foals and 'unknown' in cases where parity could not be determined based on available data. Parity data were based on foals presented for identification as part of the national Thoroughbred identification programme. This did not include foals that died prior to, or those that were not presented for, identification. Similarly, estimated per season live foal rates for mares tested as part of the SHS in 2018 and 2019 were obtained from data collected by the national Thoroughbred identification programme, which identified the 2019 foal crop in 2020 and the 2020 foal crop in 2021. Mare-level predictive factors for a live foal which were investigated included mare age, reproductive status, parity, breeding season (2018 or 2019) and geographic location. Lastly, the geographic origin of sample submissions was reported by province: Western Cape (WC), KwaZulu-Natal (KZN), Eastern Cape (EC), Northern Cape (NC), Gauteng (GP), Free State (FS) or North West (NW) and Unspecified Provinces. This included the number of horses sampled, places of examination (defined as the number of farms or other holdings at which horses were sampled), veterinary practices and submitting veterinarians per province.

Data management and statistical analysis

Data collected were stored in an Access® database (Microsoft® Corporation, Redmond, Washington, USA) that included specific queries to categorise and analyse data. Proportions were reported with Mid-P Exact 95% confidence intervals (CIs) and calculated using OpenEpi (Dean AG, Sullivan KM, Soe MM. OpenEpi: Open-Source Epidemiologic Statistics for Public Health. www.OpenEpi.com updated 2013/04/06, accessed 2021/10/29). Median ages of stallions, and maiden and barren mares were reported with the interquartile range (IQR) and range using jamovi (The jamovi project (2021). *jamovi* (version 1.6) [Computer Software]. Retrieved from https://www.jamovi.org).

The association between the identification of a live foal and candidate predictors of a successful pregnancy outcome was estimated using a generalised linear model assuming a binomial error distribution and included a random effect term for horse. This was required as some mares were observed during both observation years. Mare age was categorised as described above. Parity was categorised as no previous surviving foals in addition to four other groups based on the percentiles of the distribution. Geographic location of stud farms where mares were sampled was categorised by province and included WC, KZN, EC, NC and Other (comprising GP, FS, NW and Unspecified Provinces). The effects of factors on the identification of a live foal were first screened using univariate analyses. Univariate analysis was performed on the five candidate predictive factors of mare age, reproductive status, parity, breeding season (2018 or 2019) and geographic location. Categorical levels were combined prior to multivariable modelling when univariate screening suggested equal effect sizes. Variables were selected for multivariable models using a $p < 0.20$ criterion. Multivariable models were fitted using a manual backward stepwise approach in which variables were removed one by one until the Student's t-statistics for all remaining variables were $p < 0.05$. Associations were reported as odds ratios (OR) with their corresponding 95% CIs. Statistical modelling was performed using commercial software (IBM SPSS Statistics Version 27, International Business Machines Corp., Armonk, NY, USA).

Results

In 2018 and 2019, 1 065 and 1 207 individual Thoroughbred horses, respectively, were tested as part of the SHS. This comprised 75 stallions and 990 mares in 2018 and 77 stallions and 1 130 mares in 2019, with 136 mares being tested in both years.

Age of sampled horses

The majority of maiden mares were in the ≤ 5-year age category, with 70.5% and 71.6% in 2018 and 2019, respectively. Most barren mares were in the 6–10 and 11–15 year age categories, with 40.1% and 38.9% of barren mares in the former age category in 2018 and 2019, respectively, and 38.4% and 41.7% of barren mares in the latter age category in 2018 and 2019 respectively (Supplementary Table I). The ages of included mares were descriptively similar for the two study years (Table I).

Table I: Summary statistics of the ages (years) of Thoroughbred mares and stallions tested as part of the 2018 and 2019 South African stud health scheme

	Year	Median age	IQR	Range
All mares	2018	9	6–13	2–24
	2019	9	5–13	2–24
Maiden	2018	5	4–6	2–18
	2019	5	4–6	2–14
Barren	2018	11	9–15	4–24
	2019	11	9–14	4–24
Unspecified	2018	5	5–6	3–19
	2019	5.5	4–7	3–9
Stallions	2018	11	8–16	5–23
	2019	11	9–16	5–24

IQR – interquartile range

Mare reproductive status and reason for barren status

The proportion of unspecified reasons for classification as a barren mare descriptively decreased for the second year of the study (Table II). The most common reason for allocation as a barren mare was failure to conceive at 39.0% (2018) and 45.5% (2019) (Table II).

Parity of barren mares

The parity with the greatest proportion for barren mares was the 3–5 foal category, with 239 (36.5%) and 292 (40.4%) of barren mares in this category in 2018 and 2019, respectively (Supplementary Table II).

Foaling outcomes

A total of 2 330 and 2 097 foals born from the 2019 and 2020 foaling crops were identified in 2020 and 2021, respectively (Table III). These included foals bred from foaling, maiden and barren mares in 2018 and 2019. The proportion and percentage of foals produced by tested maiden, barren and unspecified mares cumulatively and for each reproductive status category, as well as the proportion and percentage of foals produced by mares not tested in 2018 and 2019 are summarised in Table III.

Of mares tested in 2018 and 2019, 674/990 (68.1%, 95% CI 65.1–70.9) and 715/1 130 (63.3%, 95% CI 60.4–66.1) produced foals presented for identification in 2020 and 2021, respectively (Table IV). Foaling proportions were descriptively lower in mares of the oldest age group (Table V).

Geographical origin

Samples originated from seven provinces with the majority from the WC (Supplementary Table III).

Table II: Summary of the reproductive status categorisation of Thoroughbred mares tested as part of the 2018 (*n* = 990) and 2019 (*n* = 1 130) South African stud health scheme and reason for allocation as a barren mare in 2018 (*n* = 654) and 2019 (*n* = 723)

				Reason for allocation as barren				
Year	Maiden *n* (%)	Barren *n* (%)	Unspecified *n* (%)	Failure to conceive *n* (%)	Aborted or stillborn *n* (%)	Was not bred *n* (%)	Other* *n* (%)	Not specified *n* (%)
2018	132 (13.3)	654 (66.1)	204 (20.6)	255 (39.0)	129 (19.7)	78 (11.9)	7 (1.1)	185 (28.3)
2019	391 (34.6)	723 (64.0)	16 (1.4)	329 (45.5)	168 (23.0)	129 (18.0)	26 (3.5)	71 (10.0)

* Other reasons reported by breeders included early embryonal death, loss of foal due to dystocia, death of foal within seven days of birth and euthanasia

Table III: Summary of the proportion and percentage of Thoroughbred foals identified in 2020 (*n* = 2 330) and 2021 (*n* = 2 097) that originated from mares tested and not tested as part of the South African stud health scheme in 2018 and 2019

	2018		2019	
Reproductive status	*n* (%)	95% CI	*n* (%)	95% CI
Tested mares	674/2 330 (28.9)	27.1–30,8	715/2 097 (34.1)	32.1–36.2
Maiden	92/2 330 (4.0)	3.2–4.8	277/2 097(13.2)	11.8–14.7
Barren	439/2 330 (18.8)	17.3–20.5	431/2 097 (20.6)	18.9–22.3
Unspecified	143/2 330 (6.1)	5.2–7.2	7/2 097 (0.3)	0.2–0.7
Mares not tested*	1 656/2 330 (71.1)	69.2–72.9	1 382/2 097 (65.9)	63.9–67.9

CI – confidence interval
*Presumably the majority of mares not tested constitute the category of foaling mares, as these are not included in the requirements for SHS testing

Table IV: Summary of the proportion and percentage of Thoroughbred mares by reproductive status, tested in the South African stud health scheme in 2018 and 2019, that produced a foal for identification

	2018		2019	
Reproductive status	*n* (%)	95% CI	*n* (%)	95% CI
All	674/990 (68.1)	65.1–70.9	715/1 130 (63.3)	60.4–66.1
Maiden	92/132 (69.7)	61.5–77.1	277/391 (70.8)	66.2–75.2
Barren	439/654 (67.1)	63.5–70.7	431/723 (59.6)	56.0–63.2
Unspecified	143/204 (70.1)	63.6–76.1	7/16 (43.8)	21.5–68.1

CI – confidence interval

Table V: Summary of the proportion and percentage of Thoroughbred mares by age category tested, in the South African stud health scheme in 2018 and 2019, that produced a foal for identification

Age category (years)	2018		2019	
	n (%)	95% CI	*n* (%)	95% CI
≤ 5	169/235 (71.9)	65.9–77.4	212/301 (70.4)	65.1–75.4
6–10	269/372 (72.3)	67.6–76.7	273/396 (68.9)	64.3–73.4
11–15	166/255 (65.1)	59.1–70.8	172/306 (56.2)	50.6–61.7
≥16	70/128 (54.7)	46.0–63.2	58/127 (45.7)	37.2–54.4

CI – confidence interval

Table VI: Multivariable associations between potential covariates and the observation of a live foal identified during 2020 and 2021 for 1 984 Thoroughbred maiden and barren mares and 2 120 pre-breeding screenings for venereal pathogens in South Africa

Variable	Level	Odds ratio	95% CI	*p*-value
Mare age				< 0.001
	≤ 10 years	2.91	1.91–4.42	< 0.001
	11–15 years	1.88	1.27–2.78	0.002
	≥ 16 years	Referent		
Parity	< 7 foals	0.67	0.46–0.99	0.046
	≥ 7 foals	Referent		
Province	WC & NC	3.16	1.87–5.35	< 0.001
	KZN & EC	2.35	1.37–4.05	0.002
	Other	Referent		

Factors associated with a live foal presented for identification

Mare age, parity and geographic location met the criteria on univariate screening and were selected for assessment in a multivariable model. Mare age ≤ 15 years ($p \leq 0.002$), and WC, NC, EC and KZN province of sampling ($p \leq 0.002$) were associated with increased odds of live foal identification whereas parity of fewer than seven foals reduced the odds of live foal identification ($p = 0.046$) (Table VI).

Discussion

The SHS has, since its inception more than 40 years ago, identified barren mares as those associated with a greater risk of subfertility compared with foaling mares (Marlow 2010). Furthermore, maiden mares constituted an unknown risk with regards to venereal pathogens and were therefore included for testing. This risk allocation, although arguably an oversimplification, explained the SHS's focus on these two categories for annual testing. Although young, maiden mares (typical for Thoroughbred breeding) might be at low risk of subfertility, exposure to bacterial venereal pathogens via fomites or environmental sources cannot be ruled out (Kidd et al. 2011; Schulman et al. 2013). It is therefore arguably prudent to test maiden mares of all ages for venereal pathogens prior to their addition to the national Thoroughbred breeding population to prevent introduction of venereal diseases. Since foaling mares, which constitute the largest category of mares consigned to breeding, are not included in the SHS, the analysis and findings of this study should be interpreted accordingly.

Similar to our results, the reported median age of Thoroughbred mare populations in the UK and USA was eight years and nine years in New Zealand (Allen et al. 2007; Bosh et al. 2009; Hanlon et al. 2012; Roach et al. 2021). In this report, the median age of mares categorised as barren was perhaps, unsurprisingly, slightly higher in both observation years. The median age of mares categorised by reproductive status was not available in the reports from the UK, USA and New Zealand (Allen et al. 2007; Bosh et al. 2009; Hanlon et al. 2012; Roach et al. 2021). It has been repeatedly demonstrated that mare age is an important predictor of reproductive performance (Allen et al. 2007; Bosh et al. 2009; Brück et al. 1993; Derisoud et al. 2022; Hanlon et al. 2012; Hemberg et al. 2004; Hutton & Meacham 1968; Jeffcott et al. 1982; Lane et al. 2016; Langlois & Blouin 2004; McDowell et al. 1992; Morris & Allen 2002; Nath et al. 2010; Ricketts & Alonso 1991; Rose et al. 2018; Schulman et al. 2013; Waelchli 1990). Interestingly, two maiden mares sampled in 2018 were ≥ 16 years of age. As advancing age has been shown to negatively influence the condition of the endometrium to a greater extent than parity (Morris & Allen 2002; Ricketts & Alonso 1991), older maiden mares might be at greater risk of subfertility than multiparous but younger barren mares. Indeed, neither of these maiden mares had a foal presented for subsequent identification.

The age from which reproductive performance in mares reportedly declines is essentially uniform among studies and ranged from 10 to 14 years (Allen et al. 2007; Bosh et al. 2009; Brück et al. 1993; Chevalier-Clément 1989; De Mestre et al. 2019; Hanlon et al. 2012; Hemberg et al. 2004; Hutton & Meacham 1968; Morris & Allen 2002; Nath et al. 2010; Yang & Cho 2007). Our findings seemingly supported these observations as mares ≥ 16 years old in 2018 and 2019 had a lower proportion of foals presented for identification in 2020 and 2021 compared to younger mares. Furthermore, multivariable analysis suggested that mares 11–15 years old were nearly twice as likely to have a foal presented for identification and mares ≤ 10 years old were nearly three times as likely to have a foal presented for identification compared to mares ≥ 16 years old. However, these associations might have been biased as mares ≥ 16 years of age were almost exclusively barren mares and potentially sub-fertile and additionally as data for older age categories of foaling mares were unavailable for comparison. However, barren status was not a significant predictor in univariate screening, nor did it contribute to meaningful confounding to these measured associations. Furthermore, while the observation that older mares produced fewer foals could be associated with the lower pregnancy and foaling rates expected in these mares, this might also reflect the additional contribution of increased rates of foal death or decreased foal vigour, ultimately resulting in foals of older mares not being presented for identification. It would be pertinent to determine reproductive performance of older, and indeed all age categories, of foaling mares in the South African population to better define the subfertility risk classification of all mares ≥ 14 years old.

Median stallion age in South Africa (11 years) in both observation years was the same as that reported for Thoroughbred stallions from the UK and Ireland (Roach et al. 2021). Advancing stallion age reportedly did not negatively impact either pregnancy (Davies Morel & Gunnarsson 2000; Lane et al. 2016) or live foal rates (McDowell et al. 1992). However, two reports, perhaps unsurprisingly, indicated that the oldest stallion in each study, aged 32 and approximately 23 to 25, respectively, presented with decreased fertility (Blanchard et al. 2010; Merkt & Jöchle 1993). Stallions within this extreme age range are rarely allocated to breeding and arguably the proportion of older stallions in the South African Thoroughbred population is of limited concern.

Reporting of mare reproductive status on sample submission forms improved from 2018 to 2019 with the percentage of mares allocated as "unspecified" decreasing markedly from 20.6% to 1.4%, likely due to a revised sample submission form in 2019. This more accurate allocation showed that nearly twice as many barren mares, compared to maidens were tested as part of the SHS that year. The unspecified mare group in 2018 (*n* = 204) was largely comprised of younger mares, with 125/204 (61.3%) in the ≤ 5 years and 73/204 (35.8%) in the 6–10 years age categories (Supplementary Table I) and likely to have predominantly comprised of maiden mares. Furthermore, similar proportions in 2018 (66.1%) and 2019 (64%) were barren (Table II). This additionally supported unspecified mares in 2018 as predominantly being maidens and consequently that nearly twice as many barrens as maidens were tested by the SHS in 2018. These relative proportions in the South African Thoroughbred population were similar to those reported from Ireland, Australia and New Zealand in various sampled populations (Hanlon et al. 2012; Lane et al. 2016; Nath et al. 2010).

An alternative route to estimate proportions of mares in each reproductive status category in the South African Thoroughbred population might be derived from the number of foals identified in 2020, although arguably a more accurate estimate of the proportion of mares in each reproductive status category could be derived from the number of foals identified in 2021. Again, nearly twice as many barren mares as maiden mares had foals presented for identification in 2020 and 2021. However, it is important to note that the barren mare category was comprised of both older and potentially sub-fertile mares, and thus likely underestimated the proportion of barren mares in the population. Notably, while untested mares could reasonably be expected to comprise predominantly foaling mares, this category might have included an unknown number of both maiden and barrens that were not tested. Consequently, 71% (2020) and 65.9% (2021) were likely an overestimation, however slight, of the proportion of foaling mares. Nevertheless, this was similar to the range of 64–70% of mares categorised as foaling mares reported from the northern hemisphere (Bosh et al. 2009; Lane et al. 2016; Morris & Allen 2002; Roach et al. 2021) and contrasted with reports from the southern hemisphere of foaling mares comprising a smaller proportion of Thoroughbred breeding populations at approximately 60% (Hanlon et al. 2012; Nath et al. 2010).

The proportion of barren mares in the South African Thoroughbred population cannot currently be more accurately determined chiefly due to the unknown number of foaling mares but additionally must consider factors including incomplete compliance with the SHS and reporting of both coverings and live foals. However, barrens reportedly comprised 26.4–27% of sampled mare populations in Australia and New Zealand, respectively (Hanlon et al. 2012; Nath et al. 2010). Interestingly, the proportion of barren mares in the southern hemisphere might be larger than that reported in the northern hemisphere populations (Bosh et al. 2009; Lane et al. 2016; Morris & Allen 2002). This might be associated with factors that include the relatively lower costs of keeping non-pregnant mares in the southern hemisphere (Bosh et al. 2009; Hanlon et al. 2012; Nath et al. 2010). South Africa has similar low-cost pasture-based systems to Australia and New Zealand and the difference in the reported proportions of barrens might be attributed to the number of barrens not tested and thus wrongly assumed to be foaling mares.

In our study, a similar percentage of maiden and barren mares had foals presented for identification in 2020, whereas descriptively, a greater proportion of maidens than barrens had foals presented for identification in 2021. Univariate analysis suggested that mare reproductive status was not a significant predictor of having a foal presented for identification. This supported previous reports that mare reproductive status might not have as much influence as mare age on reproductive performance (Brück et al. 1993; De Mestre et al. 2019; Lane et al. 2016; Miyakoshi et al. 2012). In contrast, several studies reported the influence of mare reproductive status on mare fertility (Allen et al. 2007; Blanchard et al. 2010; Hanlon et al. 2012; Morris & Allen 2002; Nath et al. 2010; Riddle et al. 2007; Woods et al. 1987) with maidens reportedly associated with the best performance (Allen et al. 2007; Bosh et al. 2009; Brück et al. 1993; Hanlon et al. 2012; Lane et al. 2016; Morris & Allen 2002; Nath et al. 2010; Riddle et al. 2007; Woods et al. 1987). Arguably, these previous findings might have been confounded by age.

Multivariable analysis suggested that parity of fewer than seven foals was associated with reduced odds of a mare having a foal presented for identification. This suggested a protective effect of parity on live foal rate. Seemingly, however, it is more likely that with broodmares of similar age, those with greater past reproductive success, and thus higher parity, would be preferentially retained for breeding (Chevalier-Clément 1989). Similarly, a protective effect of parity on abortion was reportedly detected when the rate of abortion decreased with increasing parity in mares of similar reproductive status and age (Chevalier-Clément 1989). However, this was similarly most likely confounded by the preferential retention of mares with successful past reproductive performance, and thus higher parity, whereas mares with poor performance, and thus lower parity, would not have been retained for breeding (Chevalier-Clément 1989). In general, when the effect of age is controlled for, mares with past reproductive success might be more likely to have reproductive success in the future. Similarly, geographical location was shown to be a significant predictor of having a foal presented for identification. However, as most stud farms are located in the WC, NC, KZN and EC provinces, this was likely confounded.

A total of 443/654 (67.7%) and 515/723 (71.2%) barren mares tested in 2018 and 2019, respectively, had a parity ≤ 5 foals (Supplementary Table II). It has been suggested that for a Thoroughbred mare to yield a positive financial return on investment over a seven-year period, a live foal should be produced in all years but one and those barren for more than one of seven years were unprofitable (Bosh et al. 2009). Therefore, failure of these mares to produce a live foal for a second successive season might risk a failed return on investment. Overall, 215/654 (32.9%) barren mares tested in 2018 and 292/723 (40.4%) barren mares tested in 2019 had no foal presented for identification in 2020 and 2021, respectively, and therefore might have been barren for a second consecutive year. Furthermore, 136 mares tested in 2018 were re-sampled in 2019. This indicated that at least 13.7% (136/990) of mares tested in 2018 failed to yield a return on investment over a seven-year period (Bosh et al. 2009). However, this cannot be clearly extrapolated and more accurate reporting of coverings and live foal numbers as well as an appropriate calculation of the costs under South African conditions are essential for definitive conclusions.

As reported on sample submission forms in 2018 and 2019, failure to conceive was a major source of loss to the industry, supporting findings reported in 1982 (Jeffcott et al. 1982). More recently, however, the most important cause of breeding losses was reported as early embryonal death (EED) (Hanlon et al. 2012; Lane et al. 2016; Morris & Allen 2002). The reported failure to conceive should be interpreted as encompassing a wide range of aetiologies including EED, which could be mistaken for failure to conceive and is greatly dependent on the stage at which pregnancy diagnosis was performed. The current South African Thoroughbred industry norm is to perform the initial pregnancy diagnosis generally at 14 days post-ovulation which would allow for detection of EED at follow-up, however it is possible that not all stud farms adhere to this norm. Barren mares reportedly have higher EED rates (Bosh et al. 2009; Hanlon et al. 2012; Morris & Allen 2002). In contrast, a more recent multivariable analysis reported that mare reproductive status was unrelated to EED (De Mestre et al. 2019).

Similar proportions of each mare age category had foals presented for identification in 2020 and 2021. Similarly, the proportions of maidens and barrens that had foals presented for identification in each year were similar. As both coverings and subsequent live foal rates are incompletely reported, their data were unavailable to more accurately estimate per season foaling rates associated with mare age and reproductive status. While per cycle pregnancy or foaling rates are preferable to per season rates (McDowell 2001; Schulman et al. 2003), these were also unavailable. Furthermore, the number of maiden and barren mares untested in 2018 and 2019 was unknown, as was the number of maidens, barrens and foaling mares consigned for cover in the course of the 2018 and 2019 breeding seasons. The estimated foaling proportion for all mares tested as part of the SHS was 68.1% and 63.3% derived from the 2020 and 2021 identification of foals, respectively. This probably underestimated actual foaling rates for maiden and barren mares for these two foaling seasons. An unknown number of foals might have suffered neonatal or later deaths or, even if surviving, were not presented for identification. Perhaps unsurprisingly, no twins were presented for identification in either season. Comparatively, between 1975 and 1979, average live foal production rate, based on information provided to the Jockey Club of Southern African (now the NHA) was 52.3% and between 1995 and 1999 was 61.4% (Schulman et al. 2003), with the increased percentage over that period being attributed to technological advancements in equine reproduction (Schulman et al. 2003). The apparent increase from 61.4% (comprising all mare categories) to the estimated 68.1% and 63.3% observed approximately 20 years later, should consider that the number of foals reported in the period 1995–1999 was based on the number of foals registered after identification and not those presented for identification. The former total may be expected to be lower, owing to factors such as foal death or injury. In recent studies that evaluated the reproductive efficiency of well-managed Thoroughbred mares in the UK, USA and Sweden, 78.3–82.7% of all mated mares produced a live foal (Bosh et al. 2009; Hemberg et al. 2004; Morris & Allen 2002). Our currently estimated foaling rates are obviously lower than these reports, and probably reflect an underestimation of the actual South African Thoroughbred population's foaling rates due to negative bias, as predominantly produce from barren mares were included in our analysis. Furthermore, not all foals survive until, or are presented for identification, and thus the number of live foals were likely under-reported. However, a strength of the current study was that mares originated from a broad range of management levels including those regarded as well-managed farms and those with more limited to marginal levels of management.

Conclusion

This was the first report of South African Thoroughbred reproductive performance since the last report over two decades ago (Schulman et al. 2003). The demographic and reproductive data derived from the 2018 and 2019 submissions provided a useful overview of the status of Thoroughbred breeding in South

Africa. Reproductive performance, measured as the per season foaling rate for sampled mares, ranged from 63.3% to 68.1%, as determined by the number of foals presented for identification, and declined with increasing mare age. Mare age, rather than reproductive status, was a significant predictor of having a foal presented for identification. Lastly, data captured via the SHS would serve to improve the accuracy of Stud Book reporting. In combination with enforcement by the NHA, of breeder-reported coverings and live foal rates (foal returns), this would allow for more accurate analysis of reproductive performance in South African Thoroughbreds.

Conflict of interest

The authors declare they have no conflicts of interest that are directly or indirectly related to the research.

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Ethical approval

The author/s declare that this submission is in accordance with the principles laid down by the Responsible Research Publication Position Statements as developed at the 2nd World Conference on Research Integrity in Singapore, 2010.

This study was approved by the University of Pretoria Animal Ethics Committee (Approval number: V096-18).

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Supplementary material

Table I: The number and percentage of Thoroughbred maiden, barren and unspecified mares, tested as part of the South African stud health scheme, comprising each age category in 2018 (*n* = 990) and 2019 (*n* = 1 130)

		Reproductive status			
Year	**Age group**	**Maiden** ***n*** **(%)**	**Barren** ***n*** **(%)**	**Unspecified** ***n*** **(%)**	**Total** ***n*** **(%)**
2018	**≤ 5**	93 (39.6)	17 (7.2)	125 (53.2)	235 (100)
	6–10	37 (9.9)	262 (70.4)	73 (19.6)	372 (100)
	11–15	0 (0)	251 (98.4)	4 (1.6)	255 (100)
	> 16	2 (1.6)	124 (96.9)	2 (1.6)	128 (100)
2019	**≤ 5**	280 (93)	13 (4.3)	8 (2.7)	301 (100)
	6–10	107 (27)	281 (71)	8 (2)	396 (100)
	11–15	4 (1.3)	302 (98.7)	0 (0)	306 (100)
	> 16	0 (0)	127 (100)	0 (0)	127 (100)

Table II: Parity category of Thoroughbred barren mares tested as part of the South African stud health scheme in 2018 (*n* = 654) and 2019 (*n* = 723)

Parity category	**2018** ***n*** **(%)**	**2019** ***n*** **(%)**
0–2	204 (31.2)	223 (30.8)
3–5	239 (36.5)	292 (40.4)
6–8	149 (22.8)	143 (19.8)
9–11	54 (8.3)	51 (7.1)
12–14	5 (0.8)	12 (1.7)
15–17	1 (0.2)	0 (0)
Unknown	2 (0.3)	2 (0.3)

Table III: Summary of the number of individual Thoroughbred horses tested, places of examination, submitting veterinary practices and individual veterinarians by province in the 2018 and 2019 South African stud health scheme

	WC		**KZN**		**EC**		**NC**		**GP**		**FS**		**NW**		**Unspecified**		**Total**	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Horses	718	744	183	223	85	115	55	64	11	55	4	1	2	2	7	3	1065	1207
Places of examination	51	43	17	17	5	10	2	3	8	7	1	1	1	1	0	0	85	82
Veterinary practices	19	18	4	4	2	3	3	2	5	7	1	1	1	1	0	0	35	36
Veterinarians	22	28	6	8	2	3	3	2	6	9	1	1	1	1	0	0	41	52

WC – Western Cape, KZN – KwaZulu-Natal, EC – Eastern Cape, NC – Northern Cape, GP – Gauteng, FS – Free State, NW – North West