Genetic analysis of calving difficulty in South African Holstein cattle

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I declare that the above dissertation is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

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I further declare that I have not previously submitted this work, or part of it, for examination at UNISA for another qualification or at any other higher education institution.

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Dedication

I dedicate this work to my family, especially my mom and son who had been supportive to me through my struggles.

Acknowledgement

I sincerely acknowledge the Lord almighty for the grace he granted me to undertake and successfully complete this study.

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Abstract

Calving difficulty is an economically important welfare-related trait in dairy cattle and, therefore, should be included in breeding objectives of South African Holstein dairy cattle. In South Africa, however, calving performance traits are not included in the national genetic evaluation programme. The present study was therefore carried out to estimate environmental and genetic influences on maternal calving difficulty in South African Holstein cattle, to develop models for genetic prediction of the trait. The final data set comprised of 14 250 calving records of 8 832 cows, from 14 herds, participating in the National Dairy Animal Recording and Improvement Scheme during the period 2009 to 2018. General Linear Models (GLM) technique was used to investigate environmental influences (SAS 2016) version 9.4. Sex of calf, parity, herd-year-season, and age of dam at calving had significant effects (P <0.05) on maternal calving difficulty. Variance components and for computing genetic parameters were estimated by the Restricted Maximum Likelihood (REML) approach using ASReml program., for variance component estimation, were included in the model. Estimates of maternal heritability effects from the linear animal model were 0.10±0.04, 0.04±0.09 and 0.12±0.10 for parities 1, 2 and 3, respectively. The estimate across all heritability were 0.04±0.04, with a repeatability model of 0.04±0.04 respectively. These estimates indicate low accuracy of selection for calving difficulty in the South African Holstein cattle population. However, these results provide the basis for computing estimated breeding values (EBVs), which will enable the reduction of calving difficulty in the South African Holstein cattle population; thus, genetic gain and performance improvement were slow.

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Chapter 1: General Introduction

1.1 Background

Reproduction is one of the most economically important traits in dairy production. It involves physiological activities such as conception, pregnancy, and calving, which are the main drivers of reproduction rate (Abdela and Ahmed, 2016). Production of a healthy calf yearly indicates efficient reproduction of a dairy cow, and the absence of regular breeding and calving decreases the profitability of a dairy enterprise (Mekonnen and Moges, 2016).

"Dystocia" (calving difficulty) is a reproductive problem and an economically important trait of major concern to the dairy industry worldwide (Abdullahpour *et al*., 2006). It can be defined as prolonged and difficult parturition that frequently requires assistance during calving (Hossein–Zadeh, 2014; Abera, 2017). Dystocia usually occurs in first-calf heifers and can lead to the death of the calf or cow if there is no urgent assistance during calving (Kaya *et al.*, 2015). Dairy cattle breeders worldwide face increasing problems caused by dystocia, which is a significant cause of peri-natal calf mortality (Ghafariana *et al*., 2014). Along with calf and cow mortality, it results in economic losses due to costs of labour and veterinary care have, and other management expenses (Steinbock *et al*., 2003; Kaya *et al*., 2015; Hickey *et al*., 2007). Dystocia has a long-term impact on animal performance, including health difficulties, reproduction challenges, decreased output, and involuntary culling (Abdela and Ahmed, 2016). All these factors directly affect the herd’s profitability, mostly by reducing the lifespan of cows in the herd and increasing the number of replacements needed. Dystocia is also a welfare problem, because it causes discomfort and harm to the cow, resulting in poor cow wellbeing (Abdela and Ahmed, 2016).

Proper herd management practices may alleviate the effects of dystocia (Newman 2008). It can be controlled through measures such as avoiding mating that cause large calves, preventing heifer obesity at calving (Kebede, 2017). Several studies, have, however, demonstrated that genetic selection and a proper breeding approach targeting better calving difficulty, might be a better option in the long term (Alam *et al*., 2017; Kebede et al. (2017), Abdela and Ahmed (2016).

Functional traits, such as health and reproduction, directly impact the costs of production and have become increasingly significant in dairy breeding goals (Pritchard *et al*., 2015). Dairy cattle breeders worldwide have increased selection emphasis on functional traits, as the focus of selection is slowly moving from traits that increase output towards those that decrease costs (Hossein-Zadeh *et al*., 2018). Previously, the primary goal of dairy cow selection was to increase milk production, increasing milk production, which unfortunately resulted in an undesirable correlated response in functional traits for example, milk production in cows is negatively correlated with fertility (Miglior *et al*., 2017). To counteract these undesired effects, attention has been shifted towards the improvement longevity, fertility, calving performance, health, and workability traits (Miglior *et al*., 2017).

In terms of global improvements in genetic assessment methodologies, the South African National Genetic Evaluation Programme has kept pace (Banga, 2009). Traits evaluated under the programme include production, conformation, longevity, and udder health. Over the past three decades or so, availability of accurate estimated breeding values (EBVs) has resulted in a significant increase in genetic merit for production and linear type traits in the major dairy cattle breeds in South Africa (Ramatsoma *et al*., 2014).

Calving performance traits are, however, not included in the national genetic evaluation programme for dairy cattle in South Africa, and there are no genetic parameter estimates for these traits in the South Africa Holstein dairy cattle. This study was, therefore, carried out to estimate genetic parameters for calving ease in South African Holstein cattle, to compute accurate EBVs for the trait, and improve it through genetic selection.

1.2 Problem statement

There is growing interest in broadening dairy cattle selection objectives worldwide to include functional traits such as calving performance (Miglior *et al*., 2017). These traits have a huge impact on dairy herd profitability and may influence cow welfare. Although there is a sustainable genetic evaluation programme, the breeding objectives for South African Holstein cattle do not include calving difficulties and there are presently no genetic parameter estimates for the calving difficulties trait. Estimates of genetic parameters are a prerequisite for computing estimated breeding values for a trait, to enable its inclusion in the breeding objective (Imbayarwo-Chikosi *et al*., 2015). Due to the absence of these parameters, accurate selection and the resultant genetic improvement in calving ease is currently not achievable in South African Holstein cattle. This study was carried out to obtain accurate estimated breeding values (EBVs) for calving difficulties by computing estimations of genetic parameters. Such EBVs will assist South African Holstein farmers will be able to precisely choose for easier calving difficulty and, therefore, improve herd profitability and cow welfare.

1.2 Aim and Objectives

The aim of the present study was to estimate genetic parameters for maternal calving difficulty in South African Holstein cattle.

The specific objectives were to:

I. Evaluate environmental factors influencing maternal calving difficulty.

II. Estimate maternal heritability of maternal calving difficulty in the first three parities, with each parity being treated as an individual trait.

III. Estimate maternal heritability of maternal calving difficulty in the first three parities, with different parities being regarded as repeated measures of the same trait.

1.3 Hypotheses

The following null hypotheses were tested:

I. Environmental effects does not influence maternal calving difficulty.

II. There is no maternal heritability of maternal calving difficulty in the first three parities, with each parity being treated as an individual trait.

III. There is neither maternal heritability of maternal calving difficulty in the first three parities, with different parities being regarded as repeated measures of the same trait.

1.4 Research outputs

1.4.1 Conference presentations

Mkhize, N.E., Mapholi, N.O., Dube, B., Madilindi, M.A. & Banga C.B. Genetic improvement of incidence of calving difficulty in dairy cattle - A Review. SA Large Herds Conference, The Boardwalk, Port Elizabeth, South Africa, 3-5 June 2019.

Mkhize, N.E., Mapholi, N.O., Dube, B., Madilindi, M.A. & Banga C.B. Genetic analysis of maternal calving difficulty in South African Holstein. 52nd Annual SASAS Congress Conference, Pretoria, South Africa, 10-12 August 2021.

Mkhize, N.E., Mapholi, N.O., B. Dube, Madilindi, M.A., O. Matika & Banga C.B. Genetic and environmental influences on maternal calving difficulty in South African Holstein cattle. Proceedings of the 11th World Congress on Genetics Applied to Livestock Production, Netherlands, to take on the 3 – 8 July 2022.

Chapter 2: Literature Review

2.1 Introduction

The background information about the South African Holstein cattle breed is presented in this chapter, including its genetic improvement programme. It is essential for genetic selection; calving performance by ensuring calving difficulty trait is improved through genetic evaluation by selecting reduced calving performance. The importance of calving difficulty in dairy production is also presented in this chapter. Non-genetic factors influencing calving difficulty and genetic parameter estimates are reviewed in this chapter.

2.2 South African dairy industry

The dairy industry is the South Africa's sixth biggest agricultural sector, and the country contributes approximately 0.4% to the world's milk production (SA Yearbook, 2019/20). Various economic activities are carried out in the industry, which involves the production of milk, raw milk, pasteurized milk and cream, fermented milk, long-life milk and cream, yogurt, and cheese, as well as their by-products (SA Yearbook, 2019/2020). The industry makes a considerable contribution to the job market in South Africa. Approximately 4,300 milk producers employ 60 000 farmworkers, and the dairy business indirectly employs another 40 000 individuals. (DAFF, 2017). According to the Department of Agriculture, Fisheries and Forestry (DAFF), South Africa has roughly 13 million cattle in 2016/17, with 1.41 million of these being dairy cows. Fresh milk consumption per capita has grown from 35.8 kilograms per year in 2010/11 to 39.0 kilograms per year in 2016/17, demonstrating that demand for fresh milk is increasing. Over the same period, this demand has been matched by a 17 percent growth in milk output (DAFF, 2018). In comparison to the previous year, the gross value of milk produced in 2018/19, comprising milk for the producer and on-farm consumption, was estimated at R277 078 million, compared to R284 622 million the previous year a reduction of 2,7% (DAFF, 2019). This decrease can be attributed to a decrease in the value of field crops and animal products.

Several organizations played various roles in establishing the South African dairy industry by dividing it into primary and secondary sectors. The primary sector comprises milk producers, and the secondary sector consists of processors and producers who sell their products directly to consumers and retailers (MPO statistic, 2021). Dairy industry matters are coordinated by Milk South Africa, an organization financed by statutory contributions. The Milk Producers' Organization (MPO) negotiates with the government and other establishments. The MPO also makes statistical and management information available to suitable producers in the dairy industry and other authorities (MPO statistics, 2021).

In South Africa, there are four prominent dairy cattle breeds: Holstein, Jersey, Guernsey, and Ayrshire, with Holstein and Jersey being the dominant ones (SA Yearbook, 2019/2020). The average national herd size is about 400 cows (Coetzee, 2017). The participation in the national milk recording scheme between commercial producers has been declining over the past decade with only 24% participation with the trend toward automatic milk systems and recording, mainly in larger.

2.3 National dairy cattle performance recording

Official milk recording began in South Africa in 1917 and managed on behalf of the South African government by the Agricultural Research Council (ARC) (Ramatsoma *et al*., 2014). The integrated registration and genetic information system (INTERGIS) is used to estimate EBVs based on the performance of dairy cattle participating in the national recording program (Mostert *et al*., 2010). The national milk recording system has evolved over time and currently tracks a variety of performance and health traits (http://www.arc.agric.za). The Scheme intends to assist the South African dairy sector in producing milk in an efficient and cost-effective manner. Automated milking systems, which require less labour and provide the benefit of automatic recordkeeping, have been adopted by the bigger dairy operations (Visser *et al*., 2020). The National Dairy Animal Recording and Improvement Scheme is managed by the Agricultural Research Council as national service on behalf of Department of Agriculture (MPO statistics, 2011; SA yearbook, 2017/18). South African livestock (beef, dairy, small stock, pig, and poultry) farmers take part in the schemes with the aim of recording properties of economic importance of their animals and to use the information derived to enhance the productivity of their herds and flocks (MPO statistics, 2011).

2.4 Dairy cattle genetic evaluation programme in South Africa

Genetic evaluation enables accurate selection of genetically superior animals for breeding to achieve genetic improvement. The National Genetic Evaluation Programme of South Africa has kept up with global improvements in genetic evaluation procedures (Banga, 2009). The traits evaluated under the programme include calving intervals, productivity, conformation, lifespan, and udder health. South Africa is now the only country from Sub-Saharan Africa to take part in the International Dairy Genetic Evaluation Programme (Interbull) (Opoola, 2019). The Ayrshire, Holstein, and Jersey dairy breeds from South Africa are participating in the Interbull evaluation program. Substantial phenotypic and genetic changes have been observed in production traits of South Africa's leading dairy cow breeds since the

1980s (Banga, 2009). Longevity, cow fertility, and udder health are all important economic features, but they were not considered in the selection process programme and there has been much concern about a reduction in these traits in this population (Makgahlela *et al.*, 2008; Banga, 2013). Therefore, broadening breeding aims for South African cattle to incorporate these traits has become increasingly important.

2.5 South African Holstein cattle breed

South Africa's most popular dairy cattle breed is the Holstein (Banga *et al*., 2014). The breed was initially brought to South Africa from the Netherlands in 1912. Duvenhage (2017) stated that the South African Friesland Cattle Breeders' Association has now changed its name to the South African Holstein-Friesland Cattle Breeders' Association. Holstein cows have a big frame and black and white markings; others have red and white spots. Holstein is a larger breed type than Ayrshire, Guernsey, and Jersey, with a mature live weight of 550 to 650 kg and the ability to calve at the age of 24 to 27 months (Bangani, 2020). Holstein heifers can be bred at 15 months of age, weighing 362.87 kg (Holstein Association, 2000).

Holstein is the highest producing dairy cattle breed, and it an economical producer of milk fat and protein (Dairy moos, 2016). With a strong growth percentage in the fattening industry, the breed also contributes to global meat supply (SA Holstein Breeders Society, 2018). These characteristics have resulted in becoming the most popular breed in South Africa. In 2019, South African Holstein cows participating in the South African National Milk Recording Scheme (2019) produced an average of 9038 kg of milk, compared to 7154 kg, 6565 kg, and 5541 kg for Ayrshire, Guernsey, and Jersey cows.

2.6 Functional traits in dairy cattle

Functional traits are the traits of an animal that help it to be more efficient lowering input costs rather than increasing output (Groen, 2004). Feed efficiency, health, fertility, and functional conformation are some of these traits. Herd management has been challenged to balance selection for production while preserving fertility, udder health, and resistance to metabolic illnesses and metabolic disorders to improve profit without compromising welfare (Egger-Danner *et al*., 2015). In the recent years, this has led to a shift in selection emphasis towards functional traits, resulting in a better balance in breeding objectives (Miglior *et al*., 2012; Zuchtdata, 2014). Functional qualities should be included in selection aims to ensure the long-term viability of dairy populations.

Research from many countries shows that farmers increasingly priorities the genetic improvement of functional traits, aiming at robust cows that are easy to handle (Steininger *et al*., 2012, Rößler *et al*., 2013, Schwarzenbacher *et al*., 2012). Higher milk yield is no longer ranked among the most important traits to select. A survey on 23 countries by Stock *et al*. (2013) showed that genetic testing for calving ease, fertility, longevity, feet and legs, and indirect health traits was highly prevalent. There are plans in several countries to further expand their recording programme in dairy cattle; these traits include efficiency, health, and fertility. (Egger-Danner *et al*., 2015).

2.6.1 Importance of calving difficulty

Calving is a key occurrence in dairy cattle productive life, and successful births are essential to the economic success of the farm. To begin producing milk, all dairy cows must give birth. In most cases, calving proceeds normally, but problems may occur before or during the calving resulting in various issues (Vanderick *et al*., 2014). Calving difficulty, often known as dystocia, is a complicated reproductive condition, which usually occurs in heifers calving for the first time. It is defined as a difficult or delayed parturition (Abdela and Ahmed, 2016, Tomka, 2018) and measures the presence or absence of calving problems and their intensities (Vanderick *et al*., 2014). A categorical scale is typically used to rate the trait, making it sensitive to subjectivity (Silvestre *et al*., 2019). Mee (2008) provides a comprehensive review of the various types of dystocia and their related risk factors in dairy cattle. Calving difficulty is of great important to the dairy industry in addition to having economic effects (Hickey *et al*., 2007, Eaglen and Bijma, 2009). Its effects can be recognized directly through higher costs of labour and veterinary expenses for assistance during calving, increased calf mortality, and reduced subsequent fertility and survival of the cow (Hickey *et al*., 2007). Following difficulties like retained placenta and longer calving period indirectly contribute to lower productivity of animals (Gaafar *et al*., 2011, Kaya *et al*., 2015, Bujko *et al*., 2018).

Furthermore, calving incidences such as hard pull support, cesarean, fetonomy, or abortion may increase infection risk (Silvestre *et al*., 2019). Calving-related infections also indirectly affect human health, as they require increased use of antibiotics. This also contaminate the cow's milk, leading to possible microbial resistance (Silvestre *et al*., 2019). Thus, it may influence the consumer's acceptability of dairy products (Mee, 2008). Dystocia, according to Abdela and Ahmed (2016) may affect calves' and dams' survival, health, and production. Dystocia can also have a severe impact on milk production and reproductive function, resulting in stillbirth, cow mortality, retained placenta, uterine infections, or increased involuntary culling (Zobel, 2013, Kaya *et al*., 2015). Thus, reducing the overall levels and severity of dystocia is vital to animal welfare and the economics of farms.

According to McGuirk *et al*. (2007), stated that the total economic costs attributable to a severe case of dystocia have been estimated at up to 500 cases. According to Mee (2008), dystocia is linked to 50 percent of calf mortality cases at delivery negatively affect cow performance (Mee *et al*., 2011). According to Tiezzi *et al*. (2018), difficulty in calving reduces the length of a cow's productive life by 10%, mainly due to increased culling risk. All these factors have a direct impact on a herd's profitability due to the shorter lifetime of the cows in the herd and the greater number of replacements required (Tiezzi *et al*., 2018).

Dystocia is a cow welfare problem, as it causes pain and injury to the cow (Kaya *et al*., 2015). Calving problems, such as stillbirth, retained placenta, and uterine infections also compromise animal welfare (Mee, 2008). Dystocia rates in dairy industries with confinement systems (e.g., the USA, The Netherlands, Canada) with similar genotypes (Holstein-Friesian) tend to be high (>5%), as compared to the other countries in Table 1. Commenting on the high dystocia rates in U.S. dairy compared to beef herds, Garry (2004) stated that dairy animals are not rigorously selected for calving ease, and management is not directed at reducing dystocia risk. In general, countries that include dystocia have a lower prevalence (e.g., Norway). However, dairy cow breed, management, and environment also play a substantial role in influencing the national dystocia rate.

Table 1: International prevalence of dystocia in Holstein Friesian dairy heifers and cows between 2001 to 2019 reported in the literature

Country	Heifer %	Cow%	Dystocia definition	Reference
France	NR	6.6	Hard pull and surgical intervention	Fourichon *et al*. (2001)
New Zealand	6.5	3.8	Calving difficulty	Xu and Burton (2003)
Australia	9.5	4.1	Severe dystocia observed, very difficult or surgical assistance	McClintock (2004)
Denmark	8.7	NR[A]	Difficult calving with or without veterinary assistance	Hansen *et al*. (2004)
Spain	3.1	2.5	Calving needed assistance and caesarean sections	Lopez de Maturana et al. (2006)
Sweden	3.9	1.9[D]	Difficult calving, unable to calve without assistance	Steinbock (2006)
UK	6.9	2.0[D]	Serious calving difficulty	Rumph and Faust (2006)
USA	22.9	13.7	Needed assistance, considerable force, and extreme difficulty	Gevrekci *et a*l. (2006)
Norway	2.7	1.1	Difficult calving	Heringstad et al. (2007)
Canada	NR[A]	6.9	Hard pull and surgery	Sewalem *et al*. (2008)
The Netherlands	NR[A]	7.8[C]	Difficult and very difficult birth	Eaglen and Bijma (2009)
Ireland	9.3	6.8	Considerable calving difficulty and veterinary assistance	Mee *et al*. (2011)
Ethiopia	11.6	NR	Considerable calving difficulty and veterinary assistance	Mekonnin *et al*. (2015)
Ireland	9.3	6.8	Considerable calving difficulty and veterinary assistance	John *et al*. (2019)

[A]Not recorded; [D]Cows only; [C]Second calves only

2.6.2 Risk factors affecting calving difficulty

Factors related to either the cow or foetus may increase the risk of dystocia in dairy cattle (Ghavi, 2014). Al-Samarai (2012) noted that maternal causes of dystocia include contraction of the birth canal and inadequacy of maternal expulsive force during calving. The constriction of the birth canal may be caused by pelvic anomalies, vulvar or vaginal stenosis, exostoses, osteomalacia, neoplasms of the vagina and vulva, vaginal cystocele, hypoplasia of the vagina and vulva, incomplete cervical dilation, carcin (Mekonnin *et al*., 2015) oma of the urinary bladder, uterine torsion, or ventral displacement of the uterus (Al-Samarai, 2012, Ghavi, 2014). Fetomaternal disproportion is a relationship between maternal and fetal factors and is the primary cause of bovine dystocia (Assefa and Adugna 2018). It can be defined as an obstruction of calf expulsion originated by the calf size/birth weight, or pelvic dimensions of the dam (Mee, 2008). Kebede *et al*. (2017) estimated that about 46% of all dystocia cases are influenced by fetomaternal disproportion. Genetics also affects the incidence of fetomaternal disproportion in cattle. The existence of variation in pelvic size among different breeds appears to be due to differences in cow body weight. However, a tendency for larger pelvic openings in larger breeds has been reported (Kebede *et al*., 2017)

2.6.3 Non-genetic factors influencing calving difficulty

Knowledge of non-genetic factors affecting calving difficulty is an important prerequisite for developing models for genetic analysis of the trait. Several factors, including the dam's age at calving, the calf's sex, parity, herd, year, and season of calving, influences calving difficulties (Szucs *et al*., 2009; (Al-Samarai, 2012, Ratshivhombela, 2020).

2.6.3.1 Age and parity of dam

The dam's age is widely known as an important cause of variation in calving difficulty, resulting in a distinct difference in the incidence of dystocia between heifers and multi-primiparous dams (Mollalign and Nibret 2016). First, calf heifers experience more calving difficulties and related calf losses than multiparous cows (Mollalign and Nibret 2016). Despite producing lighter calves at birth, first and second calf animals have been found to experience more calving difficulties than mature cows (Kebede *et al*., 2017). This may be attributable to poor pelvic development in 2-year-old heifers, which often is not fully compensated by a smaller calf (Kebede *et al*., 2017). Thus, care must be taken to ensure that heifers have reached adequate weight before they are bred.

The main causes of calving difficulty are foetopelvic Incompatibility (FPI), poor cervix dilation, uterine torsion, and weak labour (Gullstrand, 2017). Foetopelvic incompatibility is likely the most important cause of difficulties at calving in heifers (Assefa and Adugna 2018). At the same time, poor dilation, uterine torsion, and weak labour are more common in older cows. Factors such as poor dilation, uterine torsion, and inadequate delivery usually occur in both heifers and cows thus, leading to calving difficulty (Gullstrand, 2017). Johanson and Berger (2003) found that a 1dm^2 (one square diameter) increase in the pelvic area of the dam decreased the probability of difficulties at calving by 11%.

The trend of decreasing incidence of calving difficulty with increasing parity has been shown in most studies (Tomka, 2018). On the contrary, Mõtus and Emanuelson (2017) reported a higher incidence of dystocia in the third and later parities than the second one. Similarly, Juozaitienė *et al*. (2018) found exceptionally difficult calving in primiparous cows and cows at the 6th to 8th lactation. According to their observation, most of the cows that experienced difficult calving also had consecutive calving scored as difficult (Tomka, 2018).

2.6.3.2 Sex of calf

The birth weight of calves is considerably affected by their sex, and heifer calves have significantly lower birth weights than bull calves (Berry *et al*., 2007). Consequently, difficulties at calving are also more common when the calf is a bull than a heifer (Fouz *et al*., 2013). In a study on US Holsteins, the percentage of dystocia cases was 28.0% for heifers giving birth to male calves and only 6.0% for second-parity cows giving birth to female calves (Tomka, 2018). Steinbock (2006) found that Swedish Red (SRB) bull calves caused greater calving difficulty and stillbirth incidences than heifer calves in first and later parities. The same pattern has been reported in Holstein (Hickey *et al*., 2007) and Angus cattle (Gullstrand, 2017). Berry *et al*. (2007) found that giving birth to a bull calf increased the risk of difficult calving by 1.4 times, compared to giving birth to heifer calves. According to Berry *et al*. (2007), other differences between the sexes (such as conformation) may also influence calving ease since the effect of sex was still substantial even after adjusting for birth weight.

The effects of calf weight on calving difficulty may be confounded with the results of the impact of calf sex (Tomka, 2018) since male calves are born heavier than female calves. On the other hand, Piwczyński *et al*. (2013) considered the calf's bodyweight a more significant factor influencing calving difficulty than the sex of the calf.

Another reason for a higher dystocia rate for male calves is that they frequently have lengthier gestational periods, which leads to bigger or heavier calves (Tomka, 2018). Morphology also contributes to the disparity in risk of dystocia between male and female calves (Tomka, 2018).

2.6.3.3 Year and Season of calving

In a non-seasonal calving system, the calving season for different cows is variable, and this has been recognized as a factor affecting the incidence of dystocia in dairy cattle (Matilainen *et al*., 2009). Although seasons are not uniformly defined across countries, most studies have shown higher dystocia rates in winter and spring than in summer and autumn (Uematsu *et al*., 2013, Mekonnen and Moges, 2016). The possible reason for these differences is that cows were calving in winter, and spring experienced the last part of gestation in the winter. They changed or perhaps an improved feeding regime, and thus more intensive foetal growth, leading to challenging calving. This may be supported by the observation that increased temperatures during the calving month (and two preceding months) lowered the need for assistance during parturition (Tomka, 2018).

During high-temperature seasons, animals may experience heat stress. Heat stress (HS) occurs when the body temperature of the livestock increases, and they cannot dissipate body heat effectively to sustain thermal equilibrium. Thus, heat accumulates in calves and heifers, resulting in a rise in body core temperature. Sartori *et al*. (2002) established a linear regression equation to show the positive relationship between ambient temperature and body temperature in nulliparous dairy heifers (11 to 17 months old), which not only indicated the change in body temperature for heifers during HS but also suggested that heifers were more tolerant of HS than lactating cows due to fewer changes in body temperature. To adjust to HS, calves and heifers would minimize heat gain and increase heat loss. They may perish if they do not acclimatize to the high heat rise (Kadzere *et al*., 2002). This is caused by an ambient temperature exceeding the thermoneutral zone (TNZ), excessive humidity, and sluggish air movement (Bernabucci *et al*., 2002, Wang *et al*., 2020). Increased heat may affect cattle performance and reproductive, as well as increase animal mortality. It also suppresses embryonic development (Wang et al., 2020) and has a knock-on impact on neonatal calves (Tao and Dahl, 2013). Heat stress, on the other hand, has a variety of effects on embryos at various stages of development (Wang *et al*., 2020). Heat stress threatens the survival of early embryos in the first seven days by disrupting heat shock protein synthesis, oxidative cell damage, and reduced interferon-tau production, all of which are necessary for pregnancy maintenance. (Wang *et al*., 2020) and the expression of apoptosis-related genes (Fear and Hansen, 2011).

The substantial effects of the season are reflected in most statistical models for calving difficulty prediction. The combined year-season effect is mostly used, but a single impact of the season can be found or joint herd-year-season (Eriksson *et al.*, 2004). Including season into combined effects is sensible and helps to save computational costs.

2.6.3.4 Herd

In the analysis of calving difficulties, it is necessary to account for herd effects, as it has been reported to vary among different herds (Hickey *et al*., 2007, Vallée *et al*., 2013). Calving difficulty is normally measured and recorded in the herd by the farmer. They introduce some subjectivity which may present some variability or bias to the data because of the difference of opinion between herders (Vallée *et al*., 2013 Furthermore, not all calvings are monitored in the field, and the degree of observation and measurement of calving performance varies between herds. In a study of the Swedish Holstein population by Gullstrand (2017), there was a significant difference in the frequency of problematic calving between herds. Some herds had a 4.1 percent incidence rate, while others had as high as 14.3 percent. This variation could reflect farm management and practices among the herds (Bicalho *et al*., 2008, Vallée *et al*., 2013). Herd management is a significant factor in the complex incidence of dystocia in primiparous cows (Holmøy *et al*., 2017).

2.7 Genetic effects on calving difficulty

The accuracy of estimated breeding values (EBVs) is an important parameter in livestock genetic improvement. This is necessary for genetic progress through selection to take place. The phenotypic variation into components such as (co)variances owing to additive genetic influences and persistent environmental effects is part of the estimation of genetic parameters (Falconer, 2004). These indicators point to the possibility of a direct or correlated response to selection. Information on genetic parameters, such as heritability, repeatability, and genetic correlation, is a prerequisite for making efficient selection strategies by breeders to improve animal populations (Toghiani, 2012).

Calving traits are, in general, low heritable, partly because it is difficult to measure the true phenotype for all animals for categorical traits (Oldenbroek and van der Waaij, 2015). The calf's contribution (direct effect) is based on size, hormonal balance, and weight, whereas the dam's contribution (maternal impact) is based on pelvic measures and capacity to respond to parturition signalling (Eaglen *et al*., 2012, Vanderick *et al*., 2014). The maternal additive is described several times, each time a calf is born, whereas the direct additive effect is conveyed after the calf is born. The link between these genetic components becomes even more important since it may play a role in estimating genetic parameters for the trait and so modifying their responses to selection (Alam *et al*., 2017).

2.7.1 Estimation of genetic parameters for calving difficulty

Accurate estimates of breeding values for traits of economic importance are vital for genetic improvement through selection, and genetic parameters are a prerequisite to achieving this. Estimating genetic parameters involves separating phenotypic variation into components such as (co)variances attributable to additive genetic effects and permanent and temporary environmental effects is a step in estimating genetic parameters (Falconer, 2004). Genetic parameters are population-specific and do not remain constant over time, it is critical to estimate them on a regular basis for each group (Falconer, 2004).

For the genetic study of calving difficulties, linear and threshold models have been used in several research. (Wiggans *et al*., 2003, Eaglen *et al*., 2012, Vanderick *et al*., 2014). The variance estimates produced with linear models are consistently smaller than those obtained with threshold models when analysing calving ease. (Silvestre *et al*., 2019). According to Vanderick *et al*. (2014), because they were calculated on an apparent probability scale and an underlying normal scale of linear and threshold models, the heritability cannot be directly compared. However, heritability estimates are frequency dependent when a linear model is used to fit categorical traits. The advantage of threshold over linear models have been reported with simulated data (Meijering and Gianola, 1985, Hoeschele, 1988). Using field data, however, varied findings have been discovered. There have been reports of similar performance of threshold and linear models (Weller and Gianola, 1989, Matos *et al*., 1997), as well as benefits of linear models over threshold models (Carlén *et al*., 2006). Varona *et al*. (1999) showed no advantage of univariate threshold over linear models for calving ease. The analysis of calving ease with linear models yielded variance estimates that are consistently smaller than those obtained with threshold models. Thus, threshold model has not yet achieved the popularity of the linear model (Silvestre *et al*., 2019).

2.7.1.1 Heritability of calving difficulty

The degree of overall phenotypic variation in a characteristic that is due to (additive) genetic variation in individuals is known as heritability (Gullstrand, 2017). According to Borém and Miranda (2013), trait type (qualitative or quantitative), estimation technique, population variability, endogamy level of population, sample size, number and type of environments considered, and experimental accuracy are all factors that impact heritability. It is crucial in the development of breeding programs and the estimation of animal breeding values and predicting response to selection. In general, heritability for direct impacts in cattle is higher than heredity for maternal effects (Gullstrand, 2017).

Early parities have a greater estimated heritability of calving difficulties than later parities, which can be explained in part by the difference in occurrence between first and later parity cows (Gullstrand, 2017). The number of calving difficulty categories utilized in the recording method can potentially have an impact on heritability estimations. By converting heritability to the underlying normal distribution of the trait, higher estimates can be obtained. (Gullstrand, 2017).

Generally, most studies have reported the direct heritability for calving difficulty to range from 0.03 to 0.17, with those for maternal heritability ranging from 0.02 to 0.12 (Weller and Gianola, 1989, Steinbock *et al*., 2003, Wiggans *et al*., 2003, de Maturana *et al*., 2007, Eaglen *et al*., 2012). Table 2 shows heritability estimates of calving difficulty obtained from various populations, using different analytical models. Higher heritability estimates were reported using the threshold compared to linear models (Phocas and Laloë, 2003, Wiggans *et al*., 2003, Eaglen *et al*., 2012, Vanderick *et al*., 2014). This heritability estimates cannot be directly compared because they were estimated on different scales, on a visible probability scale and on an underlying normal scale for linear and threshold models, respectively (Vanderick *et al*., 2014). Even though calving ease is directly heritable from, their heritability estimates for direct and maternal heritability in a linear model were in the low range from 0.034 to 0.024 (Vanderick *et al*., 2014). The threshold model heritability estimates for direct and maternal heritability were higher, ranging from 0.117 to 0.078. The heritability estimates for linear and threshold models could not be directly compared since they were estimated on different scales. Silvestre *et al*. (2018) found that direct heritability was larger than maternal heritability, with values ranging from 0.04–0.09 and 0.01–0.02, respectively. Calving difficulties in dairy cattle was estimated to have a direct and maternal heritability of 0.03 to 0.17 and 0.02 to 0.12, respectively (de Maturana *et al*., 2007, Eaglen *et al*., 2012).

In the Korean Holstein population, Alam *et al*. (2017) found that the heritability (h2) estimates for direct and maternal components were usually low, ranging between 0.1± 0.01 and 0.060 ± 0.02. Eaglen and Bijma (2009) found similar results for second parity calving ease in Dutch Holstein dairy cattle, with direct and maternal heritability of 0.08 and 0.04 respectively. Mujibi and Crews Jr (2009) used a linear model to find comparable low heritability estimates for direct (0.14) and maternal (0.06) calving ease in Charolais cattle.

Table 2: Heritability estimates for direct effects (h^2_D) and maternal effects (h^2_M) of calving difficulty in the literature

Parity	h^2_D	h^2_M	Model (s)	Reference
1	0.043±0.0031[PH]	0.010±0.016	Linear	Silvestre *et al.* (2019)
	0.11±0.01[KM]	0.06±0.02	Linear	Alam *et al.* (2017)
	0.02 ±0.002[IH]	-	Animal	Hossein Salimi *et al*. (2017)
	0.034[WH]	0.024	Linear	Vanderick *et al*. (2014)
	0.041[IH]	0.012	Threshold	Ghiasi *et al*. (2011)
	0.03±0.17[UKH]	0.02 ±0.12	Linear	Eaglen *et al*. (2012)
	0.08±0.01[DH]	0.04±0.01	Linear	Eaglen and Bijma (2009)
2	0.02±0.003[IH]	0.002±0.001	Animal	Hossein Salimi *et al*. (2017)
	0.012[WH]	0.007	Linear	Vanderick *et al*. (2014)
	0.024 [IH]	0.012	Threshold	Ghiasi *et al*. (2011)
	0.14[CH]	0.06	Linear	Mujibi and Crews Jr (2009)
	0.086±0.0091[PH]	0.023±0.0037	Threshold	Silvestre *et al*. (2019)
	0.08±0.01[KH]	0.04±0.01	Linear	Alam *et al*. (2017)
3	0.046±0.0032[PH]	0.011±0.016	Threshold	Silvestre *et al*. (2019)
	0.117 [WH]	0.078	Threshold	Vanderick *et al*. (2014)

h^2_D=direct heritability, h^2_M=maternal heritability, PH=Portuguese Holstein, KH=Korean Holstein, IH=Iranian Holstein, CH=Charolais Holstein, DH=Danish Holstein, WH= Walloon Holstein.

2.7.1.2 Repeatability of maternal calving difficulty

Repeatability measures the degree of association between records on the same animal for traits expressed more than once in an individual's life, such as birth weight and calving ease (Toghiani, 2012). The repeatability was utilized to evaluate calving difficulties across all partners, as repeated measures of the same feature were included. According to Ghiasi *et al*. (2014), low repeatability estimates for direct and maternal calving difficulties in Iranian Holstein cows vary from 0.05 to 0.07. Klassen *et al*. (1990) found that direct and maternal repeatability for calving ease in Canadian Holstein dairy cattle were low, at 0.06 and 0.08 respectively. In the literature, there are few estimates on calving difficulties repeatability (Ghiasi *et al*., 2014). The low repeatability estimate obtained in these literatures indicate that using multiple records on an individual will be gained through extra information and accuracy.

2.7.1.3 Genetic trends of calving difficulty

Genetic trends assist farmers in evaluating the response to selection and evaluating alternative genetic improvement methods (Javed *et al*., 2007). The genetic trend represents an alteration in the average genetic value of the population per unit of time (Canaza-Cayo *et al*., 2016). Knowing your genetic development can help you set clear goals for raising a profitable and long-lasting dairy herd in the future. (Missanjo *et al*., 2013).

Heringstad *et al*. (2007) observed an increasing annual trend in the prevalence of minor calving difficulties in Norwegian Red cows, particularly in primiparous cows who had more calving problems than older cows. The levels of calving difficulty were found to be very low in the Norwegian Red population; implying low scope for genetic improvement (Heringstad *et al*., 2007). Mujibi and Crews Jr (2009) discovered a substantial genetic tendency for the direct impacts of calving ease in Charolaise cattle, but no such trend was found for maternal effects. The genetic change appears to have decreased in the following dairy population Canada, Denmark, United State of America, the United Kingdom, and Sweden (Hansen *et al*., 2004, Fatehi *et al*., 2006, Steinbock, 2006) over the years. In Denmark, genetic effects for difficult calving decreased slightly from 1988 to 1992 but increased in the following years due to intense use of Holstein sires, which resulted in increased calf size (Figure 1) (Hansen *et al*., 2004). In addition, the total genetic change per calving year was favourable for the maternal effect of calving difficulty.

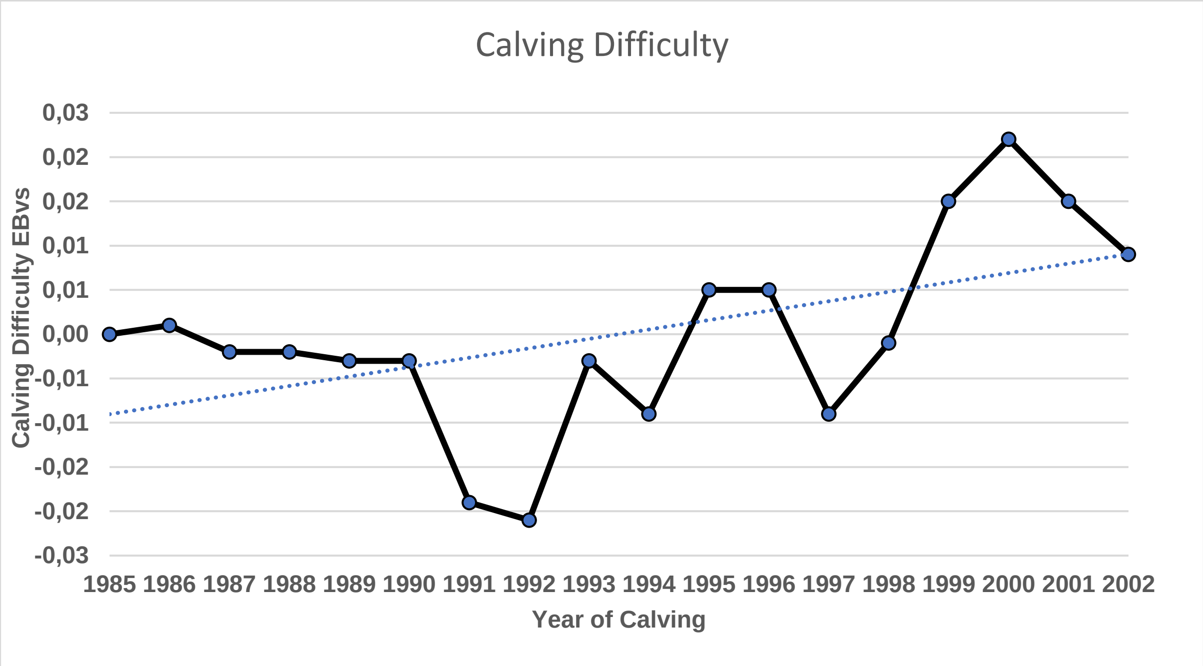


Figure 1: Genetic trend for calving difficulty of Danish Holstein population (Hansen et al., 2004)

2.8 Conclusion

Calving difficulty is an economically important trait and a major concern to dairy farmers globally. Growing concerns about animal welfare and an increase in problematic calving in dairy herds have made the characteristic even more essential. Hence, the inclusion of the trait in the selection objective for South African Holstein cattle is very important. Environmental factors such as the herd, the year and season of calving, parity, the dam's age, and the calf's sex may all have an impact calving difficulty. As a result, these characteristics must be considered in models for genetic trait assessment. Calving difficulties has been associated with low to moderate heritability estimates in the literature. This indicates low accuracy selection and, therefore, slow rates of genetic improvement for calving difficulty.

Chapter 3: Materials and Methods

3.1 Introduction

This chapter explains the processes employed in the current study for data collecting, preparation, editing, and statistical analysis. Each calving was given a score of 0 or 1, depending on whether it was normal or difficult. Animals that experienced a difficult calving were scored 1, and those that had a normal calving were scored 0. Maternal heritability of calving difficulty was estimated for each of the first three parities, as well as across the parities. Estimated breeding values for calving difficulty, which were computed using the derived variance components, were averaged by birth year to determine the genetic trends.

3.2 Data

Individual cow performance and pedigree data of South African Holstein cows from herds participating in the National Dairy Animal Recording and Improvement Scheme (NMRIS) were obtained from the Integrated Registration and Genetic Information System (INTERGIS) of South Africa, managed by the Agricultural Research Council of South Africa (ARC). From 1949 through 2018, the original data set included 10 495 603 calving records for 192 052 cows from 14 herds that documented calving problems. There were 2 642 078 animals in the pedigree file.

3.2.1 Data editing

Removal of records with missing herd identification numbers, cow identity numbers, birth dates, calving dates, or lactation numbers was done using Statistical Analysis System software (SAS Institute, 2016) version 9.4. Animals who did not have a dystocia score were also excluded from the study. Further changes were made to remove entries with missing calf sex, season, or parity information. Additionally, for the first, second, and third parities, the age of dam at calving during lactation was confined to the ranges of 20 to 37, 30 to 54, and 42 to 66 months, respectively.

Month of calving was classified into two seasons, namely summer (October - March) and winter (April- September) following recommendations from previous studies (Mostert *et al*., 2004, Dube, 2006). The modern group was classified as herd-year-season-of-calving (HYS). Contemporary groups with fewer than five animal records, as well as those with fewer than three sires, were eliminated. The final edited data set comprised of 14 250 calving records of 8 832 cows from 14 herds that calved between the years 2009 and 2018.

3.2.2 Pedigree file preparation

The pedigree file was created by considering animals with calving records and extending back three generations. Animals with unknown birth dates were removed and only sires and dams with known pedigrees were kept. The final pedigree file had 8 832 animals, daughters of 918 sires and 6 664 dams, after editing.

3.3 Statistical analysis

3.3.1 Evaluation of environmental factors influencing calving ease

Using the SAS software's General Linear Models (GLM) tool, an analysis of variance (ANOVA) was performed to see whether there were any non-genetic (environmental) variables influencing calving difficulties (SAS Institute, 2016). The herd-year-season of calving, calf sex, parity, and dam's age at calving were all tested. The analysis was conducted by fitting the following model (Equation 1):

$$y_{ijkl} = \mu + HYS_i + S_j + P_k + e_{ijkl} \quad , \qquad [1]$$

Where:

y_{ijkl} is an observation of calving difficulty (0=normal, 1=difficult);

μ is the overall population mean;

HYS_i is the fixed effect of the i^{th} herd-year-season of calving;

S_j is the fixed effect of the j^{th} sex of calf;

P_k is the fixed effect of the k^{th} parity;

β is the linear regression coefficient of dam's age at calving;

AGE is the effect of dam's age at calving;

e_{ijkl} is the random error,

It was assumed that residual errors were independent and identically normally distributed with mean 0 and variance σ_e^2, i.e.:

$e^{ijkl} \sim N\ (0, I\sigma_e^2)$

3.3.2 Estimation of genetic parameters

The Restricted Maximum Likelihood (REML) approach was used to estimate variance components for maternal calving difficulties using the ASReml program (Gilmour *et al*., 2018). Only maternal impacts of calving difficulties were incorporated in the analytical model. Because calf identification numbers were not recorded and hence not accessible in the data, direct (calf) impacts could not be included.

The following linear animal model was fitted (Equation 2):

$$y = Xb + Z_{\mathrm{a}} + e \qquad [2]$$

Where:

y is a vector of observations for calving difficulty (0=normal, 1=difficult);

b is a vector of fixed effects (herd-year-season, calf sex and parity);

a is a vector of random additive genetic effects of the cow;

X is an incidence matrix relating observations to fixed effects;

Z is an incidence matrix relating observations to random additive genetic effects;

e is a vector of random residual effects.

The (co)variance structures of the model were (Equation 3 and 4, respectively):

$$\text{Var}\begin{bmatrix} a \\ e \end{bmatrix} = \begin{bmatrix} A\sigma_a^2 & 0 \\ 0 & I\sigma_e^2 \end{bmatrix} \quad (3)$$

$$\text{Var}\,[y] = [ZAZ'\sigma_a^2 + I\sigma_e^2] \quad (4)$$

Where: A is the numerator relationship matrix; I is an identity matrix, σ_a^2 is the maternal additive genetic variance, σ_e^2 is the residual variance.

It was assumed that covariance between additive genetic effects and residual errors was equal to zero. It was further assumed that the residual errors were independent, identical, and normally distributed with variance $I\sigma_e^2$.

A repeatability animal model was used to estimate the heritability of calving difficulty across all parties, with calving in each parity being considered as a repeated measure of the same trait. The following model was fitted (Equation 5):

$$y = Xb + Za + Wpe + e \quad (5)$$

Where:

y is a vector of observations of calving difficulty;

X is an incidence matrix relating fixed effects to observations;

b is a vector of fixed effects influencing calving difficulty;

Z is an incidence matrix relating random animal additive genetic effects to observations;

a is a vector of random animal additive genetic effects;

W is an incidence matrix relating random permanent environmental effects to observations;

Pe is a vector of permanent environmental effects, to account for effects influencing the repeated calving difficulty records;

e is a vector of residual effects.

Random animal additive genetic effects (a) were assumed to have the distribution *a*~ *N* (0, $A\sigma_a^2$), where A is the additive genetic relationship matrix and σ_a^2 is the animal additive genetic variance. Residual effects (e) were assumed to be distributed with *N* ~ (0,$I\sigma_e^2$), where I is an identity matrix, σ_e^2 is the residual variance and *COV* (*a, e*) = *0.* Permanent environmental effects were assumed to be distributed with *N* ~ (0,$I\sigma_{pe}^2$), where I is an identity matrix, σ_{pe}^2 is the variance due to permanent environmental effects and *COV (pe,e)= 0, COV* (*a, pe*) = *0.*

The (co)variance structure for random effects was thus assumed to be as follows (Equation 6):

$$\mathrm{var}\begin{bmatrix} a \\ pe \\ e \end{bmatrix} = \begin{bmatrix} A\sigma_a^2 & 0 & 0 \\ 0 & I\sigma_{pe}^2 & 0 \\ 0 & 0 & I\sigma_e^2 \end{bmatrix} \qquad (6)$$

3.3.2.1 Heritability

Heritability (h^2) was calculated as the ratio of direct maternal additive genetic variance to phenotypic variance as follows (Equation 7):

$$h^2 = \frac{\sigma_a^2}{\sigma_p^2} \qquad (7)$$

Where:

h^2 = heritability estimate;

σ_a^2 = maternal additive genetic variance;

σ_p^2 = phenotypic variance.

3.3.2.2 Repeatability

Repeatability (r) was estimated as follows (Equation 8):

$$r = \frac{\sigma_a^2 + \sigma_{pe}^2}{\sigma_p^2} \qquad (8)$$

Where:

r = repeatability estimate;

σ_a^2 = maternal genetic variance;

σ_p^2 = phenotypic variance.

σ_{pe}^2 = permanent environmental variance.

3.4 Estimation of breeding values and determination of genetic trends

Estimated breeding values (EBVs) for calving difficulty in first, second and third parity were calculated by Best Linear Unbiased Prediction (BLUP) mixed model equations (Henderson, 1984) using the ASReml software (Gilmour *et al*., 2015). Using SAS software, the genetic trends were determined by computing mean EBVs by year of birth (SAS, 2012).

Chapter 4: Results

4.1 Descriptive statistics

Approximately 8% of the calving were classified as difficult. Table 3 shows the distribution of records and incidence of maternal calving difficulty by parity. The incidences ranged from 5.9 % in second parity to 9.3 % in the first parity.

Table 3: Incidence of calving difficulties in the first three parities of South African Holstein cattle

	Parity			
	First	**Second**	**Third**	**Total**
Number of calving records	6 353	4 914	2 983	14 250
Number of difficult calvings	592	289	207	1 088
Incidence of MCD (%)	9.3	5.9	6.9	7.6

MCD=Maternal calving difficulty.

4.2 Environmental factors influencing maternal calving difficulty

Table 4. Provides a summary of the analysis of variance performed to test for factors influencing calving difficulty, and a comparison of means for the significant effects. Incidence of calving difficulty was significantly affected by calf sex, parity, and herd-year-calving-season (P <0.001) and age of dam (P <0.05).

Table 4: Least squares means with standard errors and P-values for environmental factors influencing maternal calving difficulty

Factor	Least Square Means	Standard Error	P-value
Sex of calf			<.0001
Female	0.12[b]	0.003	
Male	0.14[a]	0.004	
Parity			<.0001
1	0.16[a]	0.005	
2	0.11[b]	0.004	
3	0.11[b]	0.008	
HYS			<.0001
Age of dam			<0.05

HYS=Herd-year-season; Means with the same superscript are not significantly different (*P* >0.05).

4.3 Heritability and repeatability estimates

Heritability and repeatability estimates for maternal calving difficulty in the first-three parities are presented in Table 5. Estimates of heritability were low, ranging from 0.04±0.09 in second parity to 0.12±0.10 in third parity, with an overall estimate of 0.04±0.04 across all parities. A low repeatability estimates of 0.04 was observed for MCD across the first three parities.

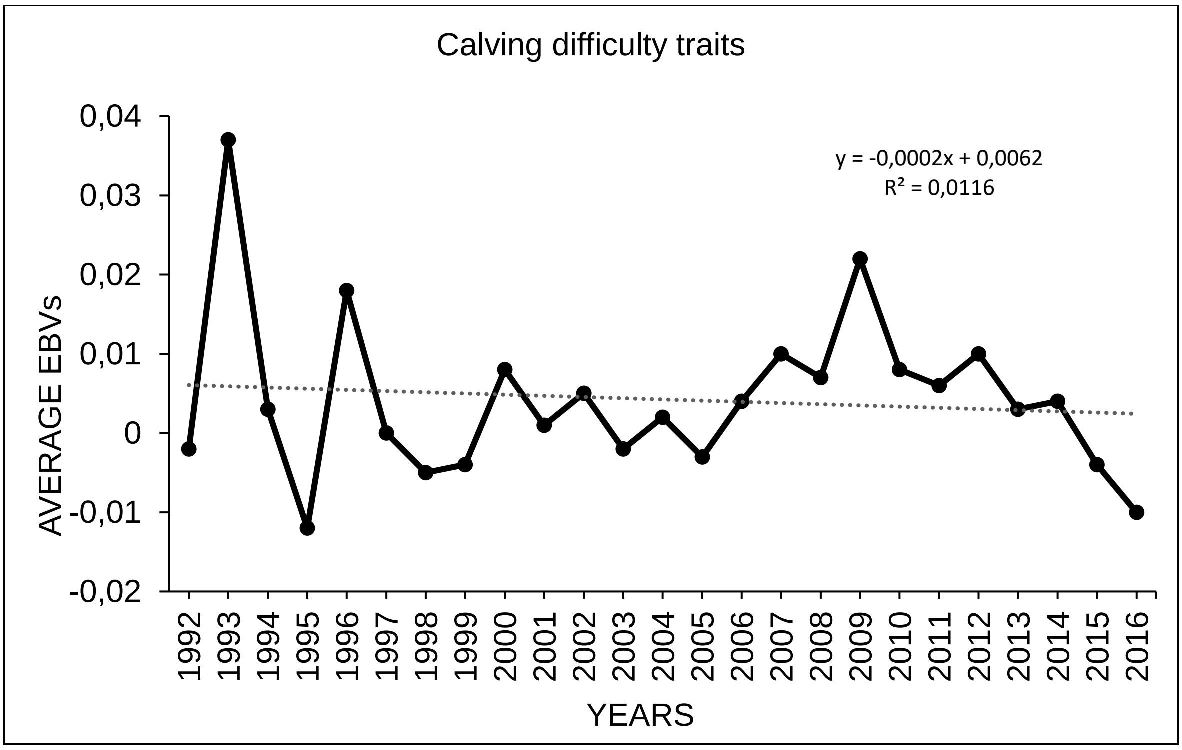
Table 5: Heritability and repeatability estimates of maternal calving difficulty within and across the first three parities in South African Holstein cows

Parity	Model	Heritability ± SE	Repeatability ± SE
1	Animal model	0.10±0.04	
2	Animal model	0.04±0.09	
3	Animal model	0.12±0.10	
All	Repeatability animal model	0.04±0.04	0.04±0.04

SE=Standard error.

4.3.1 Genetic trends

Genetic trends for maternal calving difficulty, for animals born in the period 1992 to 2016, are shown in Figure 4. Prominent peaks and dips were observed over the 24-year period. There was a noticeable increase in average EBVs in the years 1993, 1996 and 2009. A constant decrease in average EBVs was observed from 1993 to 1995 and recently from 2014 to 2016. However, the genetic trends for calving difficulty were decreasing at a rate of (-0.0002). The general trend for maternal calving difficulty was negative for the South African Holstein breed, although no statistical significances were tested.



EBVs=Estimated Breeding Values; MCD=Maternal calving difficulty.

Figure 2: Genetic trends for maternal calving difficulty in South African Holstein cattle

Chapter 5: Discussion

5.1 Introduction

This chapter discusses the main findings of the present study, comparing the results obtained to those reported in the literature and putting them into perspective. The practical application of these results, in the context of the aim of the study, is also discussed. Calving difficulty is an essential trait in dairy cattle, both economically and in terms of animal welfare. A major anticipated output of this study was accurate estimates of breeding values for calving difficulty, to enable inclusion of the traits as a breeding goal for Holstein cattle in South Africa. This would result in a decrease in the occurrence of dystocia in the population, through genetic selection.

5.2 Descriptive statistics

Causes of maternal calving difficulty (MCD) are multifactorial in nature in dairy farms and include constriction/obstruction of the birth canal and a deficiency of the maternal expulsive force (Abdel and Ahmed, 2016). The overall incidence of MCD observed in this study (7.6%) is largely comparable to a study by Mekonnin *et al*., (2015) and John *et al*., (2019). This figure is, however, relatively lower than those reported in Korean Holstein heifers (21%) by Alam *et al*. (2017). Mujibi and Crews Jr (2009) also reported a much higher incidence of about 28% of calving difficulty in first parity Charolais cattle. These differences among studies could be due, among other factors, to the fact that the trait was measured in different parities. The present study included both primiparous and multiparous Holstein cows. Previously, only primiparous Holstein cows were used in the study Alam *et al*. (2017) and Mujibi and Crews Jr (2009) only considered heifers. Limited studies have reported the incidences of calving difficulty in dairy cattle worldwide (Mujibi and Crews Jr 2009; Mekonnin *et al*., 2015; Alam *et al*., 2017 and John *et al*., 2019). A lower incidence of MCD in South Africa could also be due to under-recording of calving difficulty in dairy farms. A preliminary inspection of the data used in the study showed that most herds did not record calving performance.

5.3 Environmental factors influencing maternal calving difficulty

It was essential to determine environmental influences on calving difficulty, so that these factors are accounted for in the statistical models for estimating breeding values. Calf's sex, parity, herd-year-season, and dam's age at calving all had significant effects on maternal calving difficulty. As a result, these factors must be considered in models for genetic study of calving difficulties.

5.3.1 Sex of calf

Incidence of calving difficulty was significantly higher (P <0.001) for male than female calves, in agreement with numerous other studies (Lombard *et al*., 2007, Atashi *et al*., 2012, McHugh *et al*., 2014). This is attributable to the fact that, biologically, male calves are generally bigger in size than females, which may put more strain on the dam’s birth canal during parturition (Tomka, 2018). In addition, a higher calving difficulty for male calves is attributable to their higher body weight and also, usually, longer gestational periods which lead to bigger or heavier calves (Kebede *et al*., 2017). On the other hand, Piwczyński *et al*. (2013) considered the calf's bodyweight as a more significant factor influencing calving difficulty than sex of the calf. The use of sexed sperm has been suggested to alleviate calving difficulties caused by the calf's sex (Norman *et al*., 2009). This will achieve multiple benefits as female calves are more desirable for other reasons.

5.3.2 Parity

First-parity cows experienced a higher incidence of calving difficulty (16%) than second-parity (11%) and third-parity (11%) cows. Eaglen *et al*. (2012) and Ghafariania *et al*. (2014) reported similar findings, stating that calving assistance was greater in first-parity calvings than later-parity calvings and that calving problems were more common in heifers than cows. Roughsedge and Dwyer (2006) also found that first-calf heifers experienced more calving difficulties than cows, because of their smaller pelvic area. Similar findings have also been reported in many recent studies (Kebede *et al*., 2017, Gullstrand, 2017, Tomka, 2018). This may be due to the less developed birth canal/pelvic area of cows at first calving than in successive calvings (Kebede *et al*., 2017). Thus, care must be taken to ensure that heifers have reached adequate weight before they are bred.

5.3.3 Herd, year, and season of calving

The contemporary group was the herd-year-season of calving, and it had a considerable impact on calving difficulties. Several additional research (Ghafariania *et al*., 2014, Hossein-Zadeh, 2014, Mekonnen and Moges, 2016) supported this. A contemporary group is described as animals living in comparable environments (Nilforooshan, 2010), and it is an important component of genetic assessment models. Although seasons are not uniformly defined across countries, most studies have shown higher dystocia rates in winter and spring than in summer and autumn (Uematsu *et al*., 2013; Mekonnen and Moges, 2016). A possible reason for these differences is that cows calving in winter and spring experience the last part of gestation in winter with changed or perhaps an improved feeding regime, and thus more intensive foetal growth, leading to challenging calvings. This may be supported by the observation that increased temperatures during the calving month (and two preceding months) lowered the need for assistance during parturition (Tomka, 2018).

Gullstrand (2017) found that the incidence of calving difficulties varied greatly amongst herds in a study of the Swedish Holstein population. Some herds had incidence rates as low as 4.1 percent, while others had rates as high as 14.3 percent. This variation could reflect farm management and practices among the herds (Bicalho *et al*., 2008, Vallée *et al*., 2013). Holmy *et al*. (2017) found that herd management plays a substantial role in the complicated incidence of dystocia in primiparous cows.

5.3.4 Age of dam at calving

Potential causes of a higher incidence of dystocia in heifers and old cows were reviewed by Meijering (1984). These incidences include poor pelvic development in heifers, which is not fully compensated for by a smaller calf, reduction in the elasticity of the pelvis and accumulation of fat in the pelvic region, while substantial evidence is missing (Fiedlerová *et al*., 2008). In the current study, age of dam at calving during lactation was confined to the ranges of 20 to 37, 30 to 54, and 42 to 66 months had a significant effect (P <0.05) on maternal calving difficulty. Gaafar *et al*. (2011) similarly reported that incidence of dystocia in Friesian cows decreased significantly ($P < 0.05$) from 7.4% at 3–5 years of age to 4.6% at 11–13 years of age.

5.4 Genetic parameters

5.4.1 Heritability estimates

Heritability is one of the most essential concepts in animal breeding. It measures the strength of the relationship between the phenotype and breeding value of an individual animal (Cassell, 2009). It is important in the planning of breeding programs, estimation, of breeding values of individual animals and prediction of response to selection (Getabalew *et al*., 2019). Heritability estimates for maternal calving difficulty obtained in the current study can be used to compute estimated breeding values for maternal calving difficulty in South African Holstein cattle.

The heritability estimates obtained were generally low, ranging from 0.04±0.09 in second parity to 0.12±0.10 in third parity, with an overall estimate of 0.04±0.04 across the parities. Comparable estimates have- been reported in numerous recent studies in Holstein populations (Alam *et al*., 2017; Hossein Salimi *et al*., 2017; Silvestre *et al*., 2019). These results suggest that there is little genetic influence on maternal calving difficulty and believe the environment has a significant impact on cows' ability to give birth. This implies low accuracy of selection, which means that the rate of genetic progress would be slow if South African Holstein cattle were selected for reduced maternal calving difficulty. However, a study by Vostrý *et al*. (2014) reported much higher heritability estimates, ranging from 0.23 to 0.43 in Czech Charolais cattle. Discrepancies in heritability estimates for calving difficulty may be attributable to the way the trait is measured, and the statistical models used. According to Abdullapour *et al.* (2006*);* Hossein-Zadeh (2014*)* and Alam *et al*., (2017) calving difficulty is scored on a scale of up to 5, unlike the binary measurement used in the current study. There are, however, prospects for increasing the heritability estimates through better statistical modelling and genomics.

The variation in heritability estimates among research might be explained by the different statistical methods utilized. Considering the categorical nature of calving difficulty, from a theoretical point of view, application of a threshold model is a better choice (Silvestre *et al*., 2019). Several researchers, who used a threshold model, reported higher heritability estimates than those obtained in the current study (Phocas and Laloë, 2003; Wiggans et al., 2003; Vanderick *et al*., 2014; Silvestre *et al*., 2019). Vanderick *et al*. (2014) obtained heritability estimates for direct and maternal calving ease of 0.034 and 0.024 using linear model. The corresponding estimates with a threshold model were 0.117 and 0.078 using threshold model (Vanderick *et al*., 2014). Silvestre *et al*. (2019) reported similar estimates of 0.023 and 0.0037 for direct and maternal calving ease, respectively, using a threshold model. Technically, estimates from linear and threshold models cannot be directly compared, because they are estimated on different scales, on a visible probability scale and on an underlying normal scale for linear and threshold models, respectively.

Heritability estimates for a trait often differ between populations and might alter over time within the same population. Lower heritability estimates for calving difficulty from recent studies (Alam *et al*., 2017; Hossein Salimi *et al*., 2017) compared to those obtained in earlier years in the same population (Ghiasi *et al*., 2011) may be lower, because of a reduction in genetic variation due to selection.

The quality of performance and pedigree records used may influence the accuracy of heritability estimates. Preliminary examination of the data used in the current study discovered that calving difficulties was under-recorded in the South African Holstein population. This may have negatively impacted on the magnitude of heritability estimates obtained.

Accuracy of selection for calving difficulty in the South African Holstein population can also be improved by using a multi-trait analysis, including traits with which it is genetically correlated. For example, Eaglen *et al*. (2012) found that multi-trait models including calving ease, stillbirth and gestation length had a better predictive ability than univariate models, especially for calving ease and stillbirth.

5.4.2 Repeatability estimates

The degree to which permanent effects influence repeated trait is measured by repeatability. A low repeatability estimates of 0.04 was observed for maternal calving difficulty across the first three South African Holstein cow parities, which is comparable to the estimate of 0.05 reported in Iranian Holstein cows (Ghiasi *et al*., 2014). This implies that calving performance in the first parity cannot be relied on for prediction of future records. There are, however, limited results in the literature with which to make comparisons.

5.4.3 Genetic trends for calving difficulty

Genetic trends were determined to assess genetic change in maternal calving difficulty in the South African Holstein cattle population. The genetic trends observed in the current study showed some increase in the years from 1993, 1996 and 2009 as well as a constant decrease in the years 1993 to 1995 and from 2014 to 2016. These results show that there has been a slight increase in genetic value (i.e., undesirable trend) for calving difficulty in South African Holstein cattle over the past 24 years. Although the increase is very low, this was according to expectation since calving difficulty has not been selected against in this population. Heringstad *et al*. (2007) also found an increasing yearly trend in the incidence of calving difficulty in Norwegian Red cows. However, the levels of calving difficulty were very low in the Norwegian Red population, indicating little scope for genetic improvement. On the other hand, Hansen *et al*. (2004) reported a favourable genetic trend for calving difficulty in Danish Holstein cattle. Desirable genetic change in calving difficulty has also been observed in dairy cattle populations in Canada, Denmark, United State of America, the United Kingdom, and Sweden (Hansen *et al*., 2004, Fatehi *et al*., 2006, Steinbock, 2006), which is attributable in part to genetic selection.

Chapter 6: Conclusions and Recommendations

Genetic selection could improve calving performance, and assist in reducing the incidence of calving difficulty, which may increase herd profitability and improve animal welfare. Calving difficulty is not included in the breeding objective of South African dairy cattle, and prior to the current study, there were no estimates of genetic parameters for this trait. Thus, the current study was carried out to estimate environmental and genetic influences on calving difficulty, to develop the basis for improving it through selection in the South African Holstein cattle population.

The incidence of calving difficulties identified in the current study in the South African Holstein cattle herd is usually comparable to those described in the literature. It is, however, far lower than incidences reported in some studies, which may be attributed in part to South African farmers' under-reporting. Preliminary analysis of the data used in the current study showed that there is limited and inconsistent recording of calving difficulty on South African herds. This is likely to hamper efforts to genetically improve the trait in the population. Thus, there is a need to promote large-scale recording of calving performance on South African herds, using clear guidelines and standards.

In South African Holstein cattle, the sex of calf, parity, herd-year-season, and Age of dam at calving all have a role in maternal calving difficulties. These factors are thus important in the genetic analysis of maternal calving difficulty, and it should be incorporated in statistical models for maternal calving difficulties genetic prediction.

A low heritability was estimated for calving difficulty in the South African Holstein cattle population, which indicates that although improvement can be achieved through genetic selection, there is a need to improve the accuracy of selection. This could be achieved by selecting on both maternal and direct effects on calving difficulty. Further research may be necessary to estimate genetic correlations for both maternal and direct calving difficulty among parities using threshold models, to improve accuracy of selection.

A low repeatability estimate was observed, indicating that calving performance in the first parity cannot be relied on for prediction of future records in the South African Holstein cattle population.

An inconsistent genetic trend was estimated for maternal calving difficulty of South African Holstein cattle, which may be attributable to the fact that the trait has not been subjected in the population to selection.

The findings of this study give a solid foundation towards inclusion of calving difficulty in the breeding objective for South African Holstein cattle. In order to improve accuracy of selection, South African dairy farmers should be encouraged to record calf identification numbers and birth weight, so as to the inclusion of direct calving effects and birth weight in statistical models. Future research should also include the identification of quantitative traits loci and genes associated with calving difficulty, through genome-wide association studies, to enable marker-assisted selection.

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