Components of an Integrated Pest Management (IPM) program for the control of the sheep blowfly *Lucilia cuprina* under South African conditions

by

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DECLARATION

I declare that the thesis hereby submitted for the Ph.D. degree at the University of the Free State is my own independent work and has not previously been submitted at another university/faculty. I furthermore cede copyright of the thesis in favour of the University of the Free State.

Signed:.............................

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PREFACE

Chapters dealing with research are structured as papers, dealing with specific components of blowfly IPM. Unfortunately this has lead to the repetition of some information, especially within the Material and Methods sections. The structure of the chapters is based on personal preference but the format of the Animal Production Science Journal was used for references within the text and for the reference list.

Research on blowfly in South Africa is limited to a few scientific papers over the past decade therefore reference is predominantly made to research that was done in Australia; New Zealand and to a lesser extend the United Kingdom and America. Since *Lucilia cuprina* is the dominant blowfly species that causes flystrike in South Africa, reference will predominantly made to research that was done on this species.

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Scholtz AJ, Cloete SWP, van Wyk JB, Kruger ACM, van der Linde TCdeK (2010b) The influence of divergent selection for reproduction on the occurrence of breech strike in mature Merino ewes. *Animal Production Science* **50**, 210 - 218.

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CHAPTER 1

GENERAL INTRODUCTION

GENERAL INTRODUCTION

Wool is largely an export commodity in South Africa, in either processed or semi-processed form. In recent years South Africa has become a primarily grease wool exporter, with 20 368 metric tonnes to the value of R 915-billion shipped during the 2008/2009 season (Cape Wools (SA) 2010). This represented a 68.7% market share on total value of wool exports of R1 332-billion. The major destination was China (46.7% of total) followed by Italy (16.4%), the Czech Republic (9.7%), India (9.6%), Germany (7.9%), UK (3.1%), South Korea (1.4%), Bulgaria (1.0%) and others (4.2%) (Cape Wools (SA) 2010). Currently, key production areas are in the drier regions of the country - including the Eastern Cape (28.31% of the national wool clip), the Free State (21.28%), the Western Cape (17.29%), Northern Cape (11.00%), Mpumalanga (5.37%) and the rest (16.75% - including other provinces, Namibia and Lesotho). Wool in South Africa is produced under extensive, semi-extensive or intensive conditions.

The South African wool clip is predominantly a Merino wool clip, but coarse and coloured types are also produced on a limited scale. The bulk of the wool clip (60.2%) is produced in the fine to medium fine categories (20 - 22µ) (Cape Wools (SA) 2010). Fine and superfine qualities (<20µ) comprised 26.5% of the wool clip, while 22µ and stronger made up 13.3% of deliveries (Cape Wools (SA) 2010) (Fig. 1).

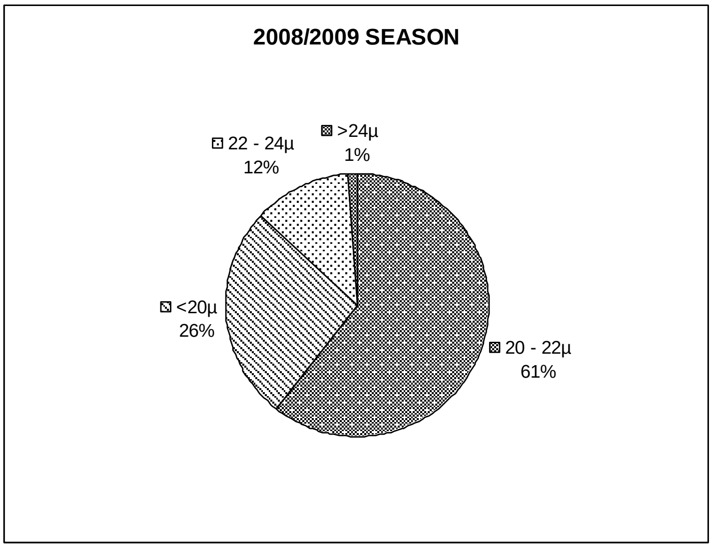

Fig. 1. Micron distribution of the South African wool clip.

The most stylish fleece wools (spinners and best top makers) comprised 16% of deliveries for the season. Almost half of deliveries of fleece wools (47.8%) qualified for good top making type (Cape Wools (SA) 2010) (Fig. 2).

Blowflies are important ectoparasites of sheep and other domestic stock in South Africa (Howell *et al*. 1978) and also occur in many of the major sheep-producing countries in the world (French *et al.* 1992). The control of blowflies and the production losses caused by flystrike are major expenses for the global sheep industry. According to a survey by Leipoldt and Van der Linde (1997) an estimated R19.8 million was lost by the wool and meat industries in South Africa during 1990. Flystrike is furthermore a major welfare problem in sheep producing countries (Morris 2000).

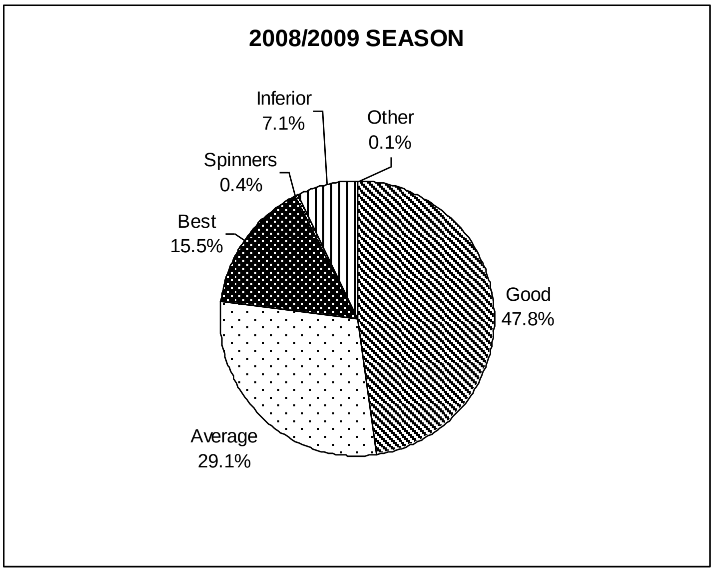

Fig. 2. Composition of the South African wool clip.

Approximately 3 - 5% of New Zealand sheep and 1.6% of sheep in England and Wales suffer from flystrike each year (Heath and Bishop 1995, French *et al*. 1992). In New South Wales, a major survey of an area containing approximately 100 000 sheep revealed a strike rate of around 2% per year over three years (Wardhaugh and Morton 1990). In a survey done in three rainfall regions in South Africa an annual strike rate of between 2 – 15%; and less than 1% mortality was reported for wool sheep (Leipoldt and Van der Linde 1997).

Although sheep strike has been recorded in other sheep producing countries (Zumpt 1965) it is the situations in Australia, New Zealand, and the United Kingdom that are most relevant to ethical decisions made by the world’s consumers, since these countries are the top exporters of wool and sheep meat, together making up approximately 76% and 78% of sheep meat and wool exports in 2007 (FAO 2010). Social attitudes to animal welfare have changed markedly in the past twenty years and in recent years surgical husbandry practices used in the management of sheep, in particular the mulesing practice, have been targeted by animal welfare campaigners as having unacceptable short term welfare implications for sheep (Colditz 2006, Hebart *et al*. 2006, James 2006, Plant 2006, Lee and Fisher 2007, Paull *et al*. 2007, Peam 2009). Welfare concerns about the pain and stress associated with the mulesing procedure, led to the Australian Wool Industry agreeing in November 2004 that mulesing will be phased out of Australia by 2010 (Colditz 2006, Leary 2006).

Even though mulesing is less widely practiced in South Africa (National Woolgrower's Association 2008), it has been a common practice in the south coast region of the Western Cape until recently. The National Council of Societies for the Prevention of Cruelty to Animals, otherwise known as the South African Animal Welfare Society (NSPCA 2009), wrote the following as a statement in their policy: '*Attitudes of individuals, as well as of communities and societies, change from time to time. Therefore what is considered to be an accepted practice to one generation may be condemned by another'.* This statement holds very true for the Mules operation, since it was considered to be the best control measure for breech strike for many generations, but is currently considered to be very cruel and unethical by the modern society.

In the NSPCA policy it is further stated that the statements in the policy must be accepted as representing current thinking but do not bind the Council nor imply any variation from the SPCA Act No 169 of 1993. It was furthermore stated that that although these issues are considered in the South African context, the Council will also seek to influence other countries where possible, and may give support to international campaigns for the protection of animals in South Africa and elsewhere in the world (NSPCA 2009). The NSPCA furthermore states that it is opposed to*:*

- *'All forms of farming and animal husbandry practices which cause suffering or distress to animals, or which unreasonably restrict their movements or their behavioural patterns which are necessary for the well-being of the species concerned'.*
- '*Mutilations or procedures, which are performed for non-therapeutic reasons, especially those carried out in an attempt to 'adapt' animals to an inappropriate husbandry system, or overcome problems associated with inappropriate husbandry systems. In such cases it is the system, not the animal, which should be modified'* (NSPCA 2009).

The South African National Wool Grower's Association (NWGA) in collaboration with the NSPCA therefore announced the following: '*The practice of mulesing is cruel and causes pain and stress to the animal and is a contravention of the Animal Protection Act no. 71 of 1962*' (National Wool Grower's Association 2009).

As a result, the need to re-evaluate the effects of husbandry practices such as mulesing has become apparent. The looming deadline of 2010 has also resulted in a push to find viable alternatives to prevent blowfly strike (James 2006, Hebart *et al*. 2006, Lee and Fisher 2007, Peam 2009) not only for Australia but for South Africa as well. It has been stated that if practical alternatives were available, then mulesing would stop tomorrow (James 2006, Plant 2006).

Furthermore, until recently blowfly strike control has largely relied on prophylactic measures based on neurotoxic insecticides such as diazinon, high cis cypermethrin, alpha cypermethrin and deltamethrin and the insect growth inhibitors, cyromazine, dicyclanil and diflubenzuron (French *et al*. 1994, Tellam and Bowles 1997, Lonsdale *et al*. 2000, Levot and Sales 2004). As is the case with most parasites that are subjected to chemical control, blowflies have also developed resistance to these insecticides (Hart 1961, Shanahan and Roxburgh 1974a, b, Arnold and Whitten 1976, Hughes and Raftos 1985, Hughes and MacKenzie 1987, Wilson and Heath 1994, Kotze *et al*. 1997, Levot and Sales 2002) and therefore these formulations might have limited use. Farmers also often use insecticides that combine flystrike prevention with louse control in one operation (Heath 2003). This means that selection pressure for resistance can operate on both parasites simultaneously (Sales *et al*. 1996), which is not a desirable outcome.

Concern about the residue implications of pesticides used in the meat trade during the mid 1980s led to the realization that harvested wool also contained pesticide residues. Environmental contamination with chemicals is also becoming increasingly less acceptable (Wilson and Armstrong 2004). This has led to the European Union's (EU) decision (October 1996) to adopt the Integrated Pollution Prevention and Control Directive (IPPC). This Directive is of concern because it forms only one part of a matrix of legislation that is applicable throughout the entire EU (Madden 2001). It reflects a comprehensive 'greening' of Europe (Madden 2001). It further means that United Kingdom and European Union wool scours need to meet risk-based environmental requirements that are much stricter than those presently operating in South Africa. As a result the UK and EU countries that import raw wool have tightened their regulations concerning chemical residues in wool. This is a trend that the South African wool industry as a primarily grease wool exporter cannot afford to ignore, since pesticide residues in wool are likely to have an impact on the future marketing of South African raw wool in Europe and the price received for it. In addition global, governmental and wool industry concerns about operator safety (Murray *et al*. 1992, Russell 1994); environmental contamination associated with the reliance on neurotoxic insecticides and the concern about residues in wool means that producers may no longer be able to rely heavily on pesticides for the control of external parasites (Russell 1994, Ward and Farrell 2000, Broughan and Wall 2006, Jordan 2009).

The sheep industry therefore has to pay more attention to the welfare and environmental issues associated with ectoparasite treatment, control and eradication (Plant 2006). Strategies other than the prophylactic use of chemicals and mulesing need to be considered and the sheep industry must move towards more sustainable techniques to manage strike; and breech strike in particular. Against this background, this dissertation investigates aspects of an integrated pest management (IPM) system for blowflies in the South Africa sheep industry. Special emphasis will be placed on breech strike, an area that has been grossly neglected prior to the actions taken by animal welfare groups and other lobbyists. Chapters dealing with research will be structured as papers, dealing with specific components of blowfly IPM. Emphasis will be placed on managerial and breeding options to address the problem by contributing to an IPM strategy.

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CHAPTER 2

LITERATURE STUDY

LITERATURE STUDY

HISTORY OF THE SOUTH AFRICAN WOOL INDUSTRY

The sheep and wool industry is one of the oldest industries in South Africa and the Merino sheep has formed the very backbone of South Africa's agricultural history for over some 200 years. In 1657 the Dutch colonialists brought sheep from Holland and crossbred them to local hairy sheep kept by the indigenous Hottentot people producing a new variety with good mutton and coarse wool (Anonymous 2009, Giles 2010). Later on, more sheep were imported from Holland and Bengal (Anonymous 2009).

The first interest in fine wool sheep was in the early 1700s when the Governor of South Africa tried to create an interest in the production of fine wool amongst farmers. Merino sheep were gradually introduced into South Africa, but no real progress was made until 1785, when Colonel Gordon imported Merinos of the Escurial stock from Spain. After his death a dispute arose between Colonel Gordon's widow and the Dutch government regarding ownership of the flock, which led to it being sold to Captain Waterhouse who took them to Australia (Anonymous 2009). During 1789, the King of Spain sent the Dutch government two Merino rams and four ewes as a gift. However, these sheep were sent to the Cape as it was thought that the climate would be more suitable there. Although carpet type wools have been produced in Northern Africa for centuries, the production of fine apparel types on the African continent only commenced with the arrival of these Merinos (Anonymous 2009, Giles 2010).

The first pure-bred Merino stud in South Africa was established by Lord Charles Somerset (in 1818) at the government farm at Malmesbury with the specific aim of distributing rams among the farming community (Anonymous 2009). By 1830 the farming of Merino sheep was well established in the Western and South western parts of the Cape. With the Great Trek in 1834, large flocks of sheep were headed eastwards and within only a few years the Merino sheep was represented throughout the country. During the entire colonial period (1806 – 1910) the Cape Province remained the most important wool producing area in Southern Africa.

By 1846 there were over 3 million sheep in South Africa, of which half were Merinos, while other types such as the Saxony, the Rambouillet and the Vermont types by then were not considered suitable for South African conditions (Anonymous 2009). It was not until the middle of 19th century, after many experiments with different strains including the Spanish Merino, the Saxon, the Rambouillet, as well as some of the English breeds that the definite South African type of Merino was established. By 1900 South Africa was importing Australian Merinos at a constant rate, since they were considered the most suitable type for the climate, but this practice was stopped with the Australian Commonwealth Government's embargo on the export of Merinos in 1929. By 1940 wool had become South Africa's most important export product after gold.

Although the sheep industry spread rapidly throughout virtually the whole of the country during subsequent years, 'Cape Wool' has become the international generic trade term for all wool produced on the sub-continent.

BLOWFLY STRIKE IN SHEEP

It is not certain when the blowfly problem emerged in South Africa, but strikes increased at the beginning of the 20th century and the problem evolved with the Wool industry (De Wet *et al*. 1986). In the early 1920s when blowflies were already a serious problem in Australia, it was predicted by Munro (1922) that blowflies might also become a serious problem in South Africa. In a study on the trapping of blowflies in the late 1920s, it was reported that the three species of blowfly implicated in attacks on sheep in South Africa were *Lucilia sericata*, *Chrysomyia albiceps* and *Chrysomyia chlorophyga* (Smit 1928). It was only in the 1960s that Zumpt (1965) reported *Lucilia cuprina* to be the principal fly involved in myiasis of sheep in South Africa. Zumpt (1965) then also reported *L. cuprina* to be the primary cause of myiasis in other African countries and in India. Currently primary blowfly species for South Africa include *L. cuprina* (Australian green sheep blowfly) responsible for 90% of all blowfly strikes followed by *Chrysomyia chlorophyga* (Wiedemann) (Copper tailed blowfly) with 10% (Howell *et al*. 1978, De Wet *et al*. 1986, Leipoldt 1996). Even though *L. sericata* has been reported to be responsible for strikes on live sheep in South Africa (Smit and Du Plessis 1927), it is of minor importance.

It is also not clear how or when the Australian sheep blowfly became established in Australia but the emergence of strike as a major industry problem in Australia seems to have coincided with 2 major events. These were the introduction of *L. cuprina*, thought to have arrived in the eastern states of Australia from South Africa or India (Gilruth *et al*. 1933, Norris 1990, Tellam and Bowles 1997) and the introduction of the extremely wrinkly Vermont Merino from the USA in the late 1800s (Graham 1979, Cameron 1999, Colditz and Tellam 2000, James 2006). It subsequently spread from there across the entire continent (Monzu 1986a). *L. cuprina* was recognized as a major pest of the sheep industry in Eastern Australia by 1915, in Western Australia by the late 1930's and by the late 1950's in Tasmania (Monzu 1986a). *L. cuprina* is also considered to be the primary myiasis fly of sheep in Australia (MacKerras and Fuller 1937, Watts *et al*. 1976, Murray 1978), being responsible for 90% of flystrike (MacKerras and Fuller 1937, Watts *et al.* 1976, Anderson *et al*. 1988) and resulting in the death of an estimated 3 million sheep annually (Broadmeadow *et al*. 1984, Wardhaugh and Morton 1990). *L. sericata* has an impact on sheep production in Australia but it is generally also regarded as of minor importance (Watts *et al.* 1976).

It is reported that *L. sericata* arrived over 100 years ago in New Zealand (Miller 1939) and it is widely distributed in the North and South Islands (Dear 1986). *L. cuprina* had been intercepted in imported cargo several times prior to 1986, but Dear (1986) was of the opinion that it was unlikely to establish in New Zealand (Holloway 1991). It is believed that *L. cuprina* became established in New Zealand since the late 1970s but that it was only reported in 1988, when its presence was confirmed throughout most regions of the North Island (Heath 1990, Heath *et al.* 1991). Cottam *et al*. (1998) reported *L. cuprina* to be the dominant strike initiator in New Zealand, although *L. sericata* was the species most prevalent in trap catches. Therefore, *L. cuprina* (Wiedemann) and *L. sericata* (Meigen) are currently the two most important blowfly species responsible for sheep myiasis in the Southern Hemisphere (Erzinclioglu 1989). In Britain, *L. sericata* is regarded as the primary agent of cutaneous myiasis in sheep (MacLeod 1943a, Tenquist and Wright 1976, MacLeod 1992, Wall *et al*. 1992a, b, Morris and Titchener 1997, Broughan and Wall 2006).

Both species (*L. cuprina* and *L. sericata*) are carrion-breeders and facultative parasites (Erzinclioglu 1989). Although these species are attracted to carrion, they rarely breed successfully in carrion due to intense competition for the food source by native Calliphorids (Waterhouse 1947, Howell *et al*. 1978). It has also been reported that blowflies changed their behaviour from living predominantly on carcasses, to being ecto-parasites, living primarily on live sheep (Howell *et al*. 1978, De Wet *et al*. 1986). The distribution of *L*. *cuprina* in Australia is closely associated with areas devoted to sheep grazing and in some regions; its status is effectively that of an obligate parasite of sheep (Anderson *et al*. 1984, 1988) although alternate breeding sites do exist (Waterhouse and Paramonov 1950, Kitching 1974, Foster *et al*. 1975, McKenzie 1984, Rice 1986, Norris 1990, Lang *et al*. 2001, Horton *et al*. 2002).

For the purpose of this study reference will primarily be made to the *Lucilia* species as well as the studies done in the abovementioned countries.

The development of flystrike

Blowfly strike (ovine myiasis) is the cutaneous infestation of sheep by the larvae of blowflies (French *et al.* 1992, MacLeod 1992, Morris and Titchener 1997). The adults are free-living and the larvae are parasitic maggots, which develop in the tissue of their host (Howell *et al*. 1978). In the spring, the larvae begin post-diapause development, leading to pupation and adult emergence (Foster *et al*. 1975, Dallwitz and Wardhaugh 1984, Wall *et al.* 1992a). The adults feed on nectar from flowering plants, although the female blowflies need a liquid protein meal to mature the eggs (Zumpt 1965, Arundel and Sutherland 1988, Daniels *et al*. 1991) and to become receptive for mating (Bartell *et al*. 1969, Heath 1985, Levot 1990). Protein may be obtained from carcasses, protein-rich dung, live susceptible or already struck sheep (Leipoldt 1996). After mating, the free flying adult female locates a susceptible sheep, commonly selecting areas soiled by faeces and/or urine or near sores or open wounds, and deposits an egg batch containing up to 250 eggs in the wool close to the skin surface of a sheep (Davies 1948, Cragg 1955, Leipoldt 1996).

The eggs hatch within eight to twelve hours and the first instar larvae feed on the weeping skin surface (Levot 1990). In the case of *L. cuprina*, first instar larvae do not have well-developed mouthparts and feed mainly on the serous exudates at the skin's surface (MacKerras and Freney 1933). The establishment of 1st stage larvae is facilitated primarily by the excretion and/or regurgitation of digestive proteases onto the ovine tissue (Sandeman *et al.* 1987, Tellam and Bowles 1997). In contrast, the second and third instars possess well-developed mouth hooks that help them to invade flesh tissue (Sandeman *et al.* 1987). The fast growing larvae invade the sheep's skin using both mechanical and enzymatic digestion (Bowles *et al*. 1988, Sandeman *et al*. 1990, Constable 1994, Tellam *et al*. 1994) burrowing into the flesh and poisoning the sheep with the ammonia that they secrete (Morris 2000). Once flystrike has been initiated, further flies are attracted to the strike site (Hall *et al*. 1995, Tellam and Bowles 1997). This is thought to be mediated by pheromones released by ovipositing females (Barton-Browne *et al*. 1969) and by bacterial odours (Emmens and Murray 1983, Arundel and Sutherland 1988).

After three to five days, during which moulting occurs twice, the fully-fed third instar larvae drop from the sheep and enter a post-feeding or wandering stage (Monzu 1986c, Wall *et al*. 1992a, Leipoldt 1996). The larvae then burrow into the soil to pupate (Monzu 1986c, Levot 1990).

The transition from maggot to adult fly occurs in the ground and is controlled by soil temperature (Monzu 1986c, Graham and Junk 2008). In cooler areas, maggots which drop off sheep in late autumn remain as larvae or prepupae in the ground during winter (Monzu 1986c, Graham and Junk 2008). When the soil temperature increases, the larvae pupate (Monzu 1986c). The length of the pupal phase is also dependent on soil temperature – the warmer the soil temperature, the shorter the pupal phase (Monzu 1986c). In warmer areas, over-wintering may be of a shorter duration or depending on temperature, not occur at all.

The abundance of primary blowflies present in an area may determine the severity and number of strikes seen, but there is a tendency for the condition to occur seasonally (Howell *et al*. 1978). The incidence of flystrike was found to increase with an increased density and activity of gravid *L. cuprina*, with rainfall determining the overall strike levels (Wardhaugh and Morton 1990). In South Africa, the appearance of the first wave of blowflies generally coincides with the first rains in spring in summer rainfall areas when adult flies emerge from the thousands of pupae in the soil (Howell *et al*. 1978). As in Australia, during the warm summer months, fly numbers generally decrease until autumn when a second wave may be produced (Howell *et al*. 1978, Monzu 1986c).

It is not uncommon for overt strikes to produce between 3000 – 9000 adult *L. cuprina* (Waterhouse 1947, Dallwitz *et al*. 1984). Even small quantities of untreated maggoty wool shorn from sheep can produce high numbers of blowflies (Anderson *et al*. 1987).

Effect of blowfly strike on the sheep

Sheep show signs of irritation during the first two days after eggs are laid (Morris 2000). Affected animals are restless, dull and reluctant to graze, and often stamp their feet (De Wet and Bath 1994) or kick at the struck area (Collins and Conington 2005). If the breech area has been struck, the sheep will shake its tail and if the affected area can be reached, the sheep will bite this area (De Wet and Bath 1994).

The feeding activity of the larvae causes extensive tissue damage and leads to considerable distress to the struck animal, and if untreated, death may occur within 3 - 6 days from the onset of the first strike (Sandeman *et al*. 1987, Guerrini 1988, Heath 2003). Secondary bacterial infection often occurs and the animal may die of septicemia or the absorption of toxins from liquefied body proteins (Collins and Conington 2005). Research found that struck sheep, compared to healthy sheep weighed less at shearing time (Fels 1971, Heath 2003), produced less wool, had up to 44% more tender fleeces and produced 17% less lambs (Fels 1971, Heath 1994). Ovine cutaneous myiasis (blowfly strike) remains the most prevalent ectoparasite-mediated disease of domestic sheep in most sheep-rearing areas throughout the world (Hall and Wall 1995).

Predisposition of sheep to flystrike

Flystrike in sheep does not occur by chance, but it is essentially due to the inherent attractiveness of a susceptible animal (Belschner and Carter 1936a, b, Belschner 1953). Early observations confirmed that animals are rendered susceptible to blowfly strike through the action of moisture (urine, sweat, dew, rainfall and bacterial activity) on predisposed sites of the body (Bull 1931, Seddon 1931, Belschner 1937b, Belschner 1953). Blowfly strike depends on the presence of moisture in the fleece, with resulting bacterial decomposition of the wool and superficial skin layers known as ‘water-rot’ or ‘fleece-rot’ (Beveridge 1934, Howell *et al.* 1978, Monzu *et al*. 1986, Raadsma 1987, French *et al*. 1995). The odour arising from such areas of decomposition attracts the female fly and stimulates her to lay eggs (Belschner 1953, James 2006). These areas of decomposition (areas of albuminous material of animal origin) (Beveridge 1934) are attractive to the blowfly before putrefactive changes take place (Bull 1931) and provide a suitable habitat for the young larvae to thrive in (Beveridge 1934, Anson and Beasley 1975, Monzu *et al*. 1986, Howell *et al.* 1978).

Types of strike

Body strike:

Strike involving any part of the body other than the breech, head and pizzle is termed ‘body strike’ (Belschner 1953, Raadsma 1987, 1991b). Most commonly affected sites are the shoulder and back regions (Belschner 1937b, Joint Blowfly Committee 1940, Raadsma 1987, Raadsma and Rogan 1987, Raadsma *et al*. 1989). The critical role of moisture in the development of body strike to enhance oviposition and to allow hatching of eggs and the development of 1st instar larvae has been indicated and demonstrated (Seddon 1931, Belschner 1953, Monzu 1986c, Vogt and Woodburn 1980). Deep skin folds which cause a ‘sweaty’ condition, tend to attract flies (Howell *et al*. 1978). Body strike is strongly weather dependent (Hayman 1953) and it is usually associated with the development of fleece rot (Belschner 1937a) and/or mycotic dermatitis (Gherardi *et al.* 1981). The major role of fleece rot and dermatophilosis in the development of body strike has been described in detail by Merritt and Watts (1978a, b), Gherardi *et al*. (1981), Watts and Merritt (1981) and Sutherland *et al*. (1983). Flystrike risk is determined by a combination of the fly population, the number of susceptible (moist protein rich sites) sheep and the suitability of the environment (maximum daily temperature must be 17°C or greater; average wind speed range must be less than 30km/hr) (Monzu and Mangano 1986a, Horton *et al*. 2001).

The dependence of body strike on seasonal conditions means that the prevalence shows considerable variation. Some years are indeed free of body strike, whereas in exceptional years, up to 50% of young sheep may be affected (Raadsma 1991a). A prevalence of 20% is considered serious with significant production losses and associated mortality (Raadsma 1991a). Young sheep, regardless of gender (Raadsma 1987), with 3 – 6 month's fleece growth are the most susceptible (Raadsma 1991a).

Breech strike:

Breech strike is a collective term for all strikes occurring on the crutch and tail region of sheep and is considered the most common form of strike in Australia; New Zealand and England (Seddon *et al*. 1931, Joint Blowfly Committee 1933, Belschner 1937a, MacKerras 1937, Belschner 1953, Anson and Beasley 1975, Watts *et al*. 1979, Raadsma 1987, Raadsma and Rogan 1987, Arundel and Sutherland 1988, French *et al*. 1995, Collins and Conington 2005). In South Africa breech strike has also been found to be more prevalent than body strike (Turpin 1947, Howell *et al.* 1978, Cloete *et al*. 2001, Scholtz *et al*. 2010b).

Breech strike occurs when the wool in the breech area becomes soiled with faeces, urine and sweat (Joint Blowfly Committee 1933, Howell *et al.* 1978, Morris 2000, Greeff and Karlsson 2005, James 2006) with the consequent development of dermatitis (Bull 1931, Seddon 1967, Greeff and Karlsson 2005, James 2006) providing a warm, moist environment for the Australian blowfly (*L. cuprina*) to lay its eggs in (Tellam and Bowles 1997).

During the 1970s, extensive surveys of flystrike occurrence in New South Wales (Watts *et al*. 1979), Western Australia (Murray and Wilkinson 1980), South Australia (Murray and Ninnes 1980), and Victoria (Murray 1980) suggested that the nature of the breech strike problem had changed significantly since the earlier part of the twentieth century (James 2006). Although earlier studies had suggested that urine staining was the major predisposing factor (Belschner 1937a, Joint Blowfly Committee 1933, Belschner 1953), the more recent surveys suggested that diarrhoea (French *et al*. 1995, 1996, 1998, Scobie *et al*. 1999), associated with grazing of improved pastures and higher stocking rates had increased markedly in importance. Faecal soiling, particularly associated with Helminth infection, has also long been recognised as a highly prevalent and strong risk factor for strikes in the United Kingdom (Leiper 1951). The major factors which influence the incidence of breech strike are: gender (with ewes more frequently affected than males), age, breed, season, wool length (MacLeod 1943b, French *et al*. 1996), tail length and conformation of the crutch area (number and position of caudal folds) (Seddon *et al*. 1931, Belschner 1937a, Watts *et al*. 1979).

Body strike and breech strike are the two forms of myiasis of greatest concern (Watts *et al.* 1979, Murray 1980, Colditz *et al*. 2006).

Other types of strike

- ***Pizzle strike*:**

  Pizzle strike occurs when urine-stained wool around the pizzle causes skin irritation and leakage of serum from the damaged skin (Bulletin No. 4128 1987). This form of strike occurs in young rams and wethers when the long wool around the preputial opening becomes soiled with urine, sometimes associated with balanitis or 'pizzle rot' (Belschner 1937a, Belschner 1953, Raadsma 1987, Raadsma and Rogan 1987). Management for the control of pizzle strike in wethers and rams includes 'ringing' - the removal of the wool from around the pizzle at crutching (Belschner 1953, Monzu *et al*. 1986) and/or 'pizzle dropping' - a less commonly used surgical procedure which eliminates the problem of urine stain in male sheep (Donnelly 1980, Marchant 1986, Monzu *et al*. 1986, Horton *et al*. 2002). Pizzle strikes are most common in high rainfall areas – particularly when sheep are in tall lush green feed (Monzu *et al*. 1986)

- ***Poll strike:***

  Poll strike or head strike is mainly confined to rams (Belschner 1937a, Monzu *et al*. 1986, Raadsma 1987, Raadsma and Rogan 1987). Poll strike (at the base of the horns in rams) may be due to infected wounds around the horns after injury caused by fighting (Monzu *et al*. 1986, Graham 1990, Horton *et al*. 2002) or moist debris and secretions around the horn bases. It can also occur when the sheep has dermatophilosis or fleece rot infections on the head (Bulletin No. 4128 1987). Poll strike occurs year-round (Monzu *et al*. 1986)

- ***Wound strike:***

  Other blowfly strikes occur where infection has set in, for example festering wounds (infected mulesing wounds: Graham 1990 as cited by Leipoldt 1996), grass seed irritation (Bulletin No. 4128 1987), infected injuries (Bulletin No. 4128 1987), perineal cancer and sheath rot (Monzu *et al*. 1986). Wound strikes are most prevalent after shearing and mulesing.

- ***Foot strike:***

  Foot-rot or foot scald can lead to foot-strike, which can then spread to the body by contact when sheep lie down (Monzu *et al*. 1986, Horton *et al*. 2002).

FACTORS THAT PREDISPOSE SHEEP TO THE VARIOUS FORMS OF FLYSTRIKE:

Fleece-rot and Dermatophilosis

Fleece rot (waterstain, weather stain, water rot, wool rot, pink rot or cakey yolk)

Fleece rot is best defined as a mild superficial dermatitis induced by moisture and bacterial proliferation at skin level (Raadsma and Rogan 1987) and manifested by seropurulent exudation resulting in a matted band of wool fibres adjacent to the skin (Raadsma 1987). Fleece discolouration is common in the dermatitis lesions, ranging from green, red orange, pink, violet and blue to the more common discolorations of yellow, grey and brown (Seddon 1937, Monzu and Mangano 1986a,b). Fleece rot develops after prolonged wetting of the fleeces and skins of susceptible sheep during the warmer months of the year under either natural or experimental conditions (Bull 1931, Belschner 1937a, b, Hayman 1953, Watts *et al*. 1980, 1981, Hollis *et al*. 1982, Raadsma *et al*. 1988, 1989). The close involvement of bacterial activity in the development of fleece rot was suspected by Seddon (1931) and later confirmed in several studies (Merritt and Watts 1978a, b, Gherardi *et al*. 1981, Watts and Merritt 1981, Sutherland *et al*. 1983). Merritt and Watts (1978b) confirmed bacterial activity of *Pseudomonas aeruginosa* in hydrolyzing the wool wax and producing extra cellular dermo-necrotizing toxins and enzymes. This activity is seen as a crucial step in the development of fleece rot (Merritt and Watts 1978b, Burrell *et al*. 1982). Subsequent scientific literature reported *P. aeruginosa* not to be the sole fleece micro organism to proliferate in fleece rot lesions and other *Pseudomonas* spp. were also implicated (Merrit and Watts 1978b, London and Griffith 1984, MacDiarmid and Burrell 1986).

Dermatophilosis (lumpy wool, mycotic dermatitis, dermo)

This condition represents dermatitis from chronic infection by the bacterium *Dermatophilosus congolensis* and is generally considered to be more severe than fleece rot. A full description of the epidemiology has been given by Roberts (1967). ‘Dermo’ scabs are found mainly on the backline, but they may extend up the neck or down the sides (Monzu and Mangano 1986b). These scabs comprise a mixture of dead skin, protein serum exudate, bacterial spores and bacterial by-products which mat the fibres together (Monzu and Mangano 1986b). Under conditions of excessive rainfall, viable and highly motile zoospores are able to invade the uncornified epidermis and elicit an acute inflammatory response (Monzu and Mangano 1986b, Raadsma 1987). The formation of thick scabs from layers of cornified epidermis cemented together with dried purulent exudate give rise to the characteristic signs of dermatophilosis in the fleece (Raadsma 1987). The disease occurs most commonly in young sheep, but, providing conditions are suitable, will spread through a flock, and sheep of all ages may become affected (Belschner 1953).

Fleece rot and dermatophilosis are the two main conditions that predispose sheep to body strike (Belschner 1937b, Merritt and Watts 1978a, b, Gherardi *et al*. 1981, Watts and Merritt 1981, Sutherland *et al*. 1983). The three main roles of fleece rot and dermatophilosis lesions in the development of flystrike are:

- Attract gravid female blowflies and encourage oviposition
- Provide moisture for eggs to hatch
- Provide soluble protein for first instar larvae to feed on (Raadsma 1987)

Body conformation

Conformational faults in the wither region of sheep have long been considered important factors predisposing sheep to fleece rot and body strike (Belschner 1937a, b, Joint Blowfly Committee 1940, Belschner 1953, Raadsma *et al*. 1987a). Extensive field studies on fleece rot on sheep identified the following three types of wither faults as being important:

- ‘High shoulder blades’;
- ‘Broad withers’ and;
- ‘Pinch’ behind the withers (Belschner 1937a, b, Joint Blowfly Committee 1940).

Of these faults Belschner (1937a, b) considered the animal which is ‘pinched’ or abnormally narrow over the fourth to sixth ribs immediately behind the posterior dorsal angle of the shoulder blade, as being the most likely to render a sheep susceptible to fleece rot. In its most exaggerated form, an obvious ‘depression’ is seen and is commonly referred to as ‘grip’ or ‘devil’s grip’ (Belschner 1953, Raadsma *et al*. 1987a). It was furthermore reported that these faults predispose the animals to fleece rot through disruption of the architecture of the fleece, resulting in an increased water penetration and retention after rain (Belschner 1937a, b, Belschner 1953, Vogt and Woodburn 1980). Hayman (1953) however claimed the wither region simply to be susceptible to fleece rot, and that conformational faults were not important. In a later study Raadsma *et al*. (1987a) supported Belschner’s previous findings by reporting that Merino sheep with the conformational fault referred to as ‘pinch’ were strongly predisposed to fleece rot dermatitis.

Tail length and conformation and anatomy of the anus and surrounding regions are reported to be factors determining propensity to dagginess in sheep (Waghorn *et al*. 1999). Vulval morphology has been implicated in urine staining (Joint Blowfly Committee 1933, Beveridge 1935b, Mules 1935, Belschner 1953). These malformations, whether genetically determined or caused by physical factors can result in persistent wool staining and an increase in breech strike susceptibility.

Fleece and skin characteristics

The numerous fleece and skin characters that have been suggested as possible indirect selection criteria are often associated with the descriptive traits used by sheep classers such as fleece colour, fleece condition, handle, character, crimp frequency and evenness, fineness, staple formation, staple length, and staple-arrangement and density (Raadsma 1987, Raadsma *et al*. 1987b). The phenotypic associations between these traits and fleece rot susceptibility have often been inconsistent (Belschner 1937b, Hayman 1953, Paynter 1961) and so of limited value in assessing their effectiveness as indirect selection criteria. Greasy wool colour has been reported to be the character most strongly related to fleece rot in South Australian Merinos (James *et al*. 1984, 1987) and is the most consistently related character in studies with other Merino strains (Holdaway and Mulhearn 1934, Belschner 1937a, Hayman 1953, Paynter 1961, McGuirk and Atkins 1980, Farquharson 1999, Karlsson *et al*. 2008).

Urine-or Faecal Stain

For 'breech strike', the predisposing condition is a 'dirty' breech. Woolly crutches collect wet faeces and urine, especially if there are crutch wrinkles and if the bare skin at the breech has not been stretched by mulesing (Fels 1971). The urine or faecal stained wool (Beveridge 1935b, Belschner 1937a, Belschner 1953, Watts and Marchant 1977, Watts *et al*. 1978, French *et al*.1996, 1998) causes skin irritation with the subsequent 'weeping' of protein-rich fluids from the inflamed skin (Bulletin No. 4128 1987). Once dirty, more faeces and urine are collected and patches of skin remain wet continuously.

The role of faecal staining in predisposition to breech strike is well established (Morley *et al*. 1976, French *et al*. 1996, 1998). The faeces attract ovipositing flies and may provide a source of protein for newly hatched larvae. Accumulations of faecal material around the tail and crutch (breech) of sheep are called dags (Reid and Cottle 1999, Waghorn *et al*. 1999). In New Zealand the greatest proportion of flystrike (80%) is breech strike as a consequence of dagginess (Heath and Bishop 1995). Dags are associated with sheep with loose, moist faeces adhering to the wool (Reid and Cottle 1999). The reasons for fluid faeces and dag formation have been reviewed by Waghorn *et al*. (1999). Reid and Cottle (1999) investigated factors involved in the adhesion of the dags to the wool. Dags can accumulate to form large masses; covering the whole rear end of a sheep, and even become dried without falling off (Reid and Cottle 1999). Increased dagginess increases the risk of flystrike (Watts and Marchant 1977, Watts *et al*. 1979, French *et al*. 1996).

The control of internal parasites still largely depends on the use of anthelmintics (Watts *et al*. 1978, Larsen *et al*. 1994, Barton *et al*. 1990). However resistance to the benzimidazole and levamisole anthelmintics was detected in 1988 and is no longer uncommon in Australia (Overend 1994, Palmer *et al*. 1998, Hucker *et al*. 1999, Rendell and Lehmann 2001), New Zealand (McKenna 1994, 1995, McKenna *et al*. 1995) or South Africa (Van Wyk *et al*. 1999, Bath 2006). Resistance to the macrocyclic lactone anthelmintics has also increased since the 1990s (Le Jambre 1993, Swan *et al*. 1994, Palmer *et al*. 2000, Ward *et al*. 2000, Rendell and Lehmann 2001, Hucker and Turner 2001, Love 2007).

Diarrhoea might occur despite the use of preventative programs to control trichostrongylid infections (Larsen *et al*. 1994). In a study in the 1970s, Anderson (1972) reported a hypersensitivity type of reaction to trichostrongylid larvae when up to 30% of four-year-old Merino wethers from their study that had worm egg counts of less than 100 eggs per gram (epg) were scouring. Larsen *et al*. (1994, 1995b) also demonstrated that scouring in adult sheep may be due to a hypersensitivity immune response to the ingestion of worm larvae. The inflammatory response of sheep to larval challenge appears to be central to the pathogenesis of dag formation (Larsen *et al*. 1994). Douch *et al*. (1995), Larsen *et al*. (1999) and Shaw *et al*. (1999) discussed possible immunological bases for this inflammatory response. Hypersensitivity scouring is difficult to prevent or predict and it therefore will not be simple to avoid the formation of dags (Larsen *et al*. 1994).

Waghorn *et al*. (1999) reported that within any flock some sheep have dags; whilst others have none and that some aspect of an individual sheep affects the initiation and accumulation of dags. These differences may include gender; tail length, wool type and length, anatomy of the anus and surrounding regions as well as physiological causes. Wether lambs tended to be more susceptible to faecal soiling and breech strike than ewe lambs in scouring mulesed sheep and this result accorded with the difference in the incidence of breech strike between the sexes (Morley *et al*. 1976). Horton and Iles (2007) reported that fewer ewes than wethers required crutching in a mixed–gender group. Scobie *et al*. (2007) in a study on Coopworth lambs reported that a gender effect became apparent, with the wethers developing a significantly higher mean dag score. They ascribed the reason for a higher accumulation of dags in the males to the difference in the bare area around the anus versus the area around the anus and vulva. In contrast, Meyer *et al*. (1983) reported that the incidence of dags varied widely over ages and seasons with the highest incidence generally observed among ewes at docking.

Ewes are more susceptible to trichostrongylid infections during the peri-parturient period (O'Sullivan and Donald 1973, Smith *et al*. 1983). Webb Ware *et al*. (1992) as cited by Larsen *et al*. (1994) reported a prevalence of severe diarrhoea of about 40% in lactating ewes at the end of the winter in south-west Victoria.

Daggy sheep are an economic burden to farmers for, in addition to direct costs, crutching removes potentially high value wool, which is sold at a heavily discounted price (Meyer *et al*. 1983, Larsen *et al*. 1994, 1995a). Larsen *et al*. (1995a) reported that sheep with increased breech soiling ('dag') required significantly more labour to remove the dag prior to shearing. Furthermore the presence of dags has also been found to double the time taken to crutch a lamb (Scobie *et al*. 1999). Daggy or stained wool, even when cleaned, carries into the final product, causing appearance and performance problems (Scobie *et al*. 1997). Scobie *et al*. (1997) furthermore reported that dags in sheep have detrimental consequences on the saleability of livestock in New Zealand due to the impact on slaughter hygiene.

Wrinkles

The Merino sheep breed is valued for its fine quality wool and one of the most distinguishing characteristics of the fine wool breeds is the presence of skin folds or wrinkles (Bosman 1933, Jones *et al*. 1946, Morris 2000). The raised folds on the skin of Merino sheep and related breeds are variously called wrinkles, ribs, folds or pleats and the sheep carrying them are referred to as wrinkly, developed or pleated (Scobie *et al*. 2005a). Sheep that are free of wrinkles are sometimes called plain-bodied or flat-skinned (Scobie *et al*. 2005a).

The optimum level of skin wrinkles for a Merino flock has long been a matter of debate (Belschner *et al*. 1937, Carter 1943, Austin 1947, Belschner 1953, Baillie 1979, Atkins 1980). Research into wrinkles on Merino sheep began back in the 1920s in the United States, when Spencer *et al*. (1928) showed that the American Rambouillet sheep with smooth skin produced less greasy wool than those with skin wrinkles. Historically wool was sold on the basis of total greasy weight, and reports from the United States acknowledge that this was still the case in the 1950s (Shelton *et al*. 1953) This state of affairs resulted in the introduction of the 'super-wrinkly' Vermont Merinos in the Australian flock during the late 1800s that gave a Merino with increased skin folds over most of the body (Townend 1987). The increased quantity of greasy wool obtained from wrinkly sheep resulted in the use of skin wrinkles as an indirect selection criterion for greasy fleece weight in Merino and related breeds (Scobie *et al*. 2005a).

However Bosman (1934) and Belschner and Carter (1936 a, b), reported that sheep with smooth skin produce wool of higher clean yield and Belschner *et al*. (1937) showed that the higher yield meant that clean fleece weight, and therefore the amount of useful wool, was not different between smooth and wrinkly sheep. Bell *et al*. (1936), in a comparative study on fleeces growth by American and Tasmanian Merinos, confirmed this by stating the following '*Apparently the higher percentage content of grease and dirt in American fleeces imparted a fullness and compactness that was readily misjudged (by manual methods) as density. Among wrinkly, short-stapled, greasy fleeced American Merino rams this feeling of fullness and compactness, due to grease and dirt, resulted in gross misjudgment of density to the extent that the estimate of their wool-producing capacity was a serious misconception*'. Bell *et al.* (1936) repeatedly found that the comparatively plain-bodied Tasmanian Merino sheep possessed from 8 - 20 thousand more wool fibers per square inch of skin than the wrinklier American Merino. Belschner (1953) reported on the fact that greasy fleece weight wasn't necessarily an indication of clean wool production nor was the manual method used in the estimation of density satisfactory. He furthermore reported that compactness of density of the fleece was not merely determined by the number of fibers per unit area, but also by the average thickness (diameter) of these fibers and their degree of stiffness and rigidity. Length of staple, the amount of yolk and dust surrounding the fibers, the type of yolk (that is whether it is firm and sticky or soft and fluid) also make their contribution to the feeling of compactness or otherwise when the fleece is actually handled (Belschner 1953). Atkins (1980) reported that selection for increased skin fold led to a moderate increase in greasy fleece weight, but as wool yield was lower, there was only a small increase in clean fleece weight. The increase in surface area resulting from folds was largely offset by a decline in wool production per unit area, principally from a reduced staple length (Robards *et al*. 1976). Similar results were reported for the CSIRO wrinkle selection flocks by Turner *et al*. (1970) as cited by Atkins (1980), where the high wrinkle flock cut no more wool than the control. The length of the harvested staple is a function of the length grown and the length removed during shearing, and the presence of skin wrinkles makes it difficult to cut all the staples at the same height above the skin. Turpin (1947) also reported the superfluous skin development on the body of South African Merino sheep to be unnecessary, since even without it, a high level of wool production could be attained. Scientific literature from South Africa further reported smooth sheep to produce wool staples with less variability in length (Rose 1929, Bosman 1933). From Australia (Belschner and Carter 1936a, b, Belschner *et al*. 1937) and America (Jones *et al*. 1944) it was reported that smooth sheep produced wool of longer staple length than wrinkled sheep. Flocks selected for high and low levels of skin fold; the Fold Plus and Fold Minus flocks, were established at Trangie in 1951 and maintained until 1972. As the Trangie Folds Plus sheep had higher feed requirements for maintenance than control flock animals (Robards *et al*. 1976), selecting for increased skin folds is clearly a very inefficient method of selecting for increased fleece weight.

During the early 1930's, Belschner and Carter (1936a, b) also showed that smooth Australian sheep produced wool of better quality, whatever 'better quality as assessed by a wool classer' meant at that time. This was a little better defined in South Africa, where diameter and diameter variability were found to be greater on the tops of the wrinkles than on the skin beside them (Duerden 1929, Reimers and Swart 1929, Bosman 1933). Similarly, Bell *et al*. (1936) found that wool of 56's spinning count grew on the crest of the wrinkle and 70's quality on the skin between. These quality numbers (spinning count) were defined as the official grade standards of the United States Department of Agriculture, and indicated that the wool was finer on the skin between the wrinkles. More recently, Sutton *et al*. (1994, 1995) showed that fibers on the wrinkle tend to be shorter and have a larger diameter, greater variability of diameter and more fibers over the threshold that can cause a prickling sensation in finished garments worn against the skin (>30 µm). This was associated with lower follicle density in the wrinkles (Sutton *et al*. 1995).

However, the most deleterious correlated response to selection for wrinkles occurred in fitness characters (Atkins 1980). Dun (1964a) defined 'constitution' as a sheep's ability to survive, produce, and reproduce under harsh environmental conditions and reported a strong association between wrinkles and poor constitution with selection for wrinkles an important factor influencing reproduction and survival of Merino sheep. Further confirmation of the strong unfavourable association between wrinkles and reproductivity was provided by Carter and Belschner (1937), Gill and Graham (1939, 1940), Kennedy (1959) and Dun (1961). Dun (1964a) estimated a net reproductive rate (the number of ewe hogget replacements produced by a ewe in her lifetime) for Folds Plus ewes at 1.248, compared to 2.270 for Folds Minus ewes. Dun and Wall (1962) reported a poor lambing performance for the Folds plus flock with 10% fewer twins mothered and 12% more wet ewes without lambs at foot. Earlier findings estimated a negative genetic correlation between reproductive performance of ewes and their fold score in the Trangie population (McGuirk 1973 as cited by Atkins 1980). Wastage from the breeding flock due to deaths or necessary culling was higher among the Folds Plus ewes, and the reproductive performance of the Folds Plus flock was poorer due largely to a higher proportion of dry ewes, and higher lamb losses between birth and weaning (Atkins 1980). The difference observed in the percentages of wet ewes underestimates the true difference between the Folds Plus and Folds Minus flocks as higher proportion of Folds Plus rams were rejected for poor semen quality prior to joining (Dun 1964a, McGuirk 1969). Dun and Hamilton (1965) attributed the total difference in flock fertility between these two groups to differences in ram fertility. Baillie (1979) reported heavily developed rams to be more prone to heat infertility than plainer rams.

Reproduction is of paramount importance in the South African sheep industry where meat typically contributes largely to the income of wool farmers (Olivier 1999). The demand for meat has favoured the selection of plain-bodied animals, which have faster growth rates and higher lambing percentages (Olivier and Cloete 1998, Poggenpoel and van der Merwe 1987) thus resulting in an improved total income (Londt and McMaster 1998). The correlation between plain-bodied animals and 'constitution' (as per definition) was confirmed by Dun (1964a), Rose (1976), Baillie (1979), Donnelly (1979) and Atkins (1980) reporting that smooth sheep have higher conception rates, more twins and lower mortality of ewes and lambs at birth, and their better performance in Australia tends to be highlighted during drought conditions. Another spin-off from a higher lambing percentage is that the greater numbers available for flock replacements offers the potential for faster genetic gain in a flock (Baillie 1979). Scientific literature also reported that smooth sheep produce more and faster growing lambs that are less likely to get flystrike (Baillie 1979, Scobie *et al*. 2005a).

The importance of breech wrinkle in determining susceptibility to breech strike was also recognized very early in the history of the sheep industry (Froggatt 1915, Froggatt and Froggatt 1916, 1917, 1918, Bull 1931, Seddon 1931, Seddon *et al*. 1931, Joint Blowfly Committee 1933, Beveridge 1935a, MacKerras 1937). For many years, sheep-breeders (probably more particularly those in South Australia) have realized that sheep with smooth bodies were less susceptible to blowfly attack than the wrinkly bodied sheep (Bull 1931). Although this opinion was strongly held by some, there was no demonstration of the part played by wrinkles and folds, especially those in the breech, until Seddon *et al*. (1931) divided sheep into broad categories on the basis of breech conformation, described as: A-type, relatively insusceptible (Fig. 1a); B-type, moderately susceptible; and C-type, definitely susceptible (Fig. 1b).

A good association between this classification and susceptibility to strike was demonstrated by Seddon *et al*. (1931) (Fig. 2); The Joint Blowfly Committee (1933) and MacKerras (1936, 1937). Seddon and Belschner (1937) later provided a detailed description of the features of sheep in the three classes. These early studies also showed that liability to strike was broadly parallel to the degree of wrinkling in the breech area and that susceptibility to breech strike was repeatable, with the same sheep likely to be re-struck each season (Seddon *et al*. 1931).

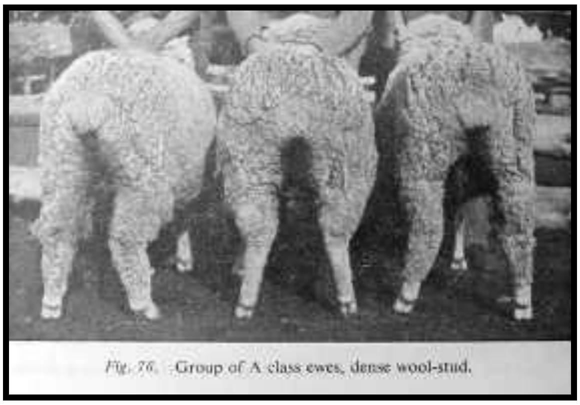

Fig. 1a

Fig. 1b

Fig.1a and b. Seddon *et al*. (1931) categorized sheep on the basis of breech conformation: A, relatively insusceptible and C, definitely susceptible (Belschner 1953)

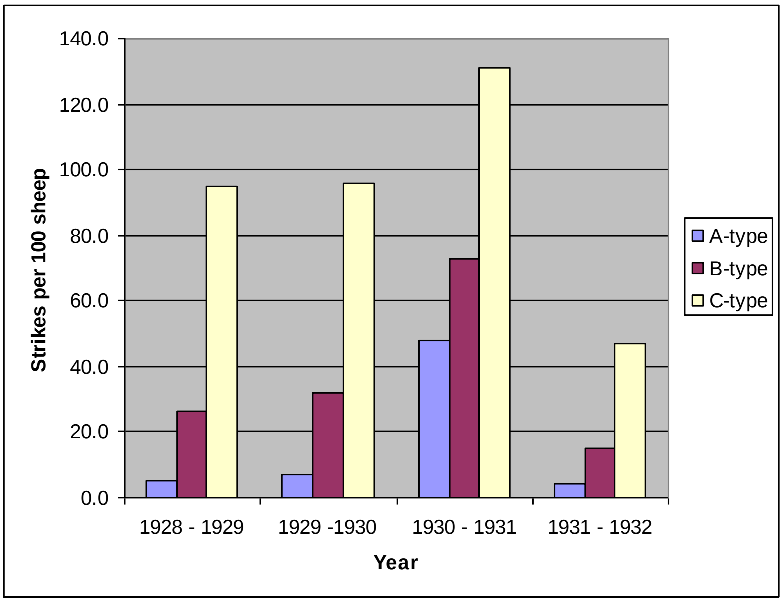

Fig. 2. The association between classification type (A-type = plain breech, B-type= intermediate, C-type = wrinkly) and incidence of strikes as demonstrated by Seddon *et al*. (1931) for the (1928 -1931 seasons) and Belschner (1937a) for the 1931 – 1932 season

However, these early genetic research findings were not generally adopted by the sheep breeding industry, probably in response to two developments in the 1930's. Firstly; the introduction of the 'Mules operation' in 1932 by Mr. G. Mules from South Australia following an offer of financial rewards for solutions to the blowfly problem (Cameron 1999) and secondly: by the 1930s easier to apply chemicals for blowfly control started to become readily available. In 1937 MacKerras reported the following '*Whether the elimination of breech wrinkles can best be achieved by operation of by breeding must be left to the stud and flock masters*'. Although it was well recognized that heavily developed sheep were more susceptible to breech strike and posed additional management problems, producers were reluctant to breed a plain-bodied Merino on the grounds that wool production would decline (Atkins 1980, Townend 1987, James 2006).

Scobie *et al*. (2005a, b) reviewed the evidence that wrinkly Merino sheep are more susceptible to flystrike than those with smooth skins and presented new evidence that sheep with less wrinkles grew faster, were more fecund, were faster to shear and produced more valuable pelts at slaughter. Given that Scobie *et al*. (2005b) also found negligible superiority in either fibre diameter or fleece weight of wrinkly sheep, a less wrinkly Merino with a bare breech that does not require mulesing would seem a profitable selection goal for sheep breeders to consider.

THE CONTROL OF BLOWFLY STRIKE

The control of blowfly strike relies on suppressing the blowfly population on the one hand and reducing the susceptibility of sheep to blowfly strike on the other. Methods that can be used in the control of flystrike are listed below:

Methods to reduce susceptibility of sheep

- Methods that can be used to reduce susceptibility to blowfly strike include the following:
  - *Prophylactic use of pesticides (Seddon 1967, Anson and Beasley 1975);*
  - *Tail-docking (Gill and Graham 1939, Riches 1942, Graham et al. 1947);*
  - *Mulesing (Bull 1931, MacKerras 1935, Seddon 1935, Gill and Graham 1938, 1939, 1940, Graham et al. 1941, Dun 1964b);*
  - *Strategic shearing (Belschner 1953, Mangano 1986, French et al. 1996);*
  - *Crutching (McCulloch and Howe 1935, McCulloch 1932, 1933, 1937, 1938, Graham et al. 1947, Shanahan and Morley 1948, Belschner 1953, Graham 1954, Anson and Beasley 1975);*
  - *Dagging (French et al. 1992, Scobie et al. 1999);*
  - *Control of internal parasites (Morley et al. 1976);*
  - *Breeding for resistance (Belschner 1953, Watts et al. 1979);*
  - *The selective application of pesticides (Russell 1994, Armstrong 2003).*

- The following method was researched but was found to be impractical:
  - *Vaccines against Fleece rot (Tellam and Bowles 1997) and blowfly larvae (Colditz et al. 2006).*

Methods to control blowfly populations

- In combination with reduced susceptibility, the blowfly population can be controlled by making use of:
  - *Fly traps (French et al. 1992).*

- The following method was also researched but does not appear to be useful at this time:
  - *Sterile Insect Release Method (Horton et al. 2002, Bell and Sackett 2005.*

Integrated Pest Management (IPM)

Integrated Pest Management (IPM) is the systematic approach of the control of blowfly strike and relies on the use of more than one and preferably several of the abovementioned methods acting cumulatively. An IPM program includes consideration of animal welfare, environmental, economic and occupational health and safety concerns (Karlsson 1999, Karlsson *et al*. 2001, Jordan 2009).

Control programs that rely on the continued use of chemicals are seldom sustainable because of the inevitable development of resistance to these chemicals, potential health risks as well as environmental impact. An Integrated Pest Management (IPM) program is used to reduce reliance on chemicals and to achieve long-term, sustainable and profitable production (Evans and Karlsson 2000, 2001a, b). IPM emphasizes alternative non chemical methods to prevent and manage many diseases and pests (Evans and Karlsson 2001a, b).

For the purpose of this study the different practices/methods that can be used in an Integrated Pest Management program to control blowfly strike will be discussed under the following headings:

- Traditional Methods
  - *Chemicals*
  - *Mulesing*
- Managerial Methods
  - *Strategic Shearing and Crutching (including dagging and pre-lamb crutching)*
  - *Tail-docking*
  - *Selective use of chemicals*
  - *Control of internal parasites*
  - *Paddock/environment management*
- Population Control Methods
  - *Fly trapping*
  - *SIRM*
- Other Methods
  - *Vaccination*
- Breeding for Resistance
  - *Direct selection*
  - *Indirect selection - correlated traits*

Traditional methods

Chemicals

Until recently blowfly strike control has largely relied on prophylactic measures based on neurotoxic insecticides throughout the growing season (French *et al*. 1994d, Tellam and Bowles 1997, Lonsdale *et al*. 2000, Levot and Sales 2004). This leads to residues in the fleece at shearing (Russell 1994). Some of the insecticide backline treatments applied in long wool have occasionally been associated with a reversible irritant reaction in shearers and wool handlers (Russell 1994) and are therefore perceived to be health hazards.

Concern about the residue implications of pesticides used in the meat trade during the mid 1980's led to the realization that harvested wool also contained pesticide residues. Pesticides associate strongly with the wax on the wool and are substantially removed from the wool during processing, however, the presence of even trace residues is antagonistic to the 'natural', environmentally friendly image of wool (Russell 1994).

Blowflies have also developed resistance to some or all of these insecticides (Monzu 1986b, Shanahan and Roxburgh 1974, see more detail in Chapter 1) and therefore insecticides currently available might be of limited use. The sheep industry therefore has to pay more attention to environmental issues associated with ectoparasite treatment, control and eradication (Plant 2006).

Strategies other than the prophylactic use of chemicals need to be considered and this has challenged the sheep industry to move towards more sustainable techniques to manage strike, and breech strike in particular.

Mulesing

The Mules operation was the first surgical measure to be applied in animal disease prevention (Beveridge 1935a). Mulesing is a drastic surgical operation used to reduce the number of skin folds (wool bearing skin) on the breech of lambs (Bull 1931), allowing the natural bare area to stretch considerably around the perineum (Belschner 1953, Fels 1971, Luff 1976, Scobie *et al*. 1999, Edwards *et al*. 2009). The stretched bare area does not produce wool, limiting the retention of faeces and/or urine (Belschner 1953, Luff 1976, Morley and Johnstone 1983, 1984, Edwards *et al*. 2009), thereby making the breech less attractive to flies and dramatically lowering the incidence of breech strike (Luff 1976, Raadsma 1991a, Scobie *et al*. 1999, Colditz 2006, Lee and Fisher 2007). Mulesing is usually performed with tail docking during the first 12 weeks after birth and provides protection especially through the usually vulnerable weaner stage and for the remaining life of the sheep (Luff 1976).

Mulesing - The development of the different forms of the procedure

Mulesing was developed when the only effective method of preventing breech strike was crutching (McCulloch and Howe 1935, Bell and Sackett 2005). Better knowledge of breech strike and a better understanding of the features that determine susceptibility have led to the development of the Mules operation in its various forms, together with the tail-strip procedure (Chapman 1993, James 2006).

Early studies identified the importance of breech folds in determining susceptibility to strike (Seddon *et al*. 1931, MacKerras 1937) and the publication of these results stimulated the development of the earliest form of the Mules operation by the South Australian Grazier Mr. J.W.H. Mules in 1931 (Beveridge 1984, James 2006). James (2006) stated that largely as a result of the Vermont influence, most Merinos of the early 1930s had extensive wrinkling in the breech area and in particular a pair of medial folds that ran vertically along each side of the perineal area. The mulesing technique was aimed primarily at removing these folds to aid in the control of blowfly strike (Mules 1935, Seddon 1935, MacKerras 1937, Beveridge 1984, James 2006). Mr. Mules used lambs, which were pure Peppin blood that varied in age from about three weeks to about eight weeks and removed the main fold extending downwards at the lateral borders of the perineum (Bull 1931, Seddon 1935, Beveridge 1984). For the operation the lamb was placed on the buttocks and the hind limbs extended and held close to the body of the animal (Bull 1931). The operation consisted of clamping the folds in the ‘jaws’ of the ‘Burdizzo’ castrating instrument, a procedure that was thought to paralyze the nerve endings, and then excising the clamped folds with a knife (Bull 1931, Beveridge 1935a, 1984, Morley and Johnstone 1984). The great pressures applied by the instrument brought the edges at the base of the fold together and made them adhere, at the same time sealing the blood vessels (Bull 1931). Bull (1931) furthermore reported that there was absolutely no haemorrhage and no tendency for the edges to separate.

A subsequent modification in 1935 by Mr. Mules was the use of roll-cut secateurs (Beveridge 1935a, MacKerras 1935) and later on adapted dagging shears, which improved the utility of the operation (Beveridge 1984, Morley and Johnstone 1984, James 2006). Beveridge (1935a) suggested, that in lambs showing only small wrinkles, one or two cuts with the secateurs on each side were usually sufficient to render them insusceptible to blowfly strike. It was also suggested that even though no wrinkles could be seen, if desired, plain lambs could also be treated by producing an elliptical wound commencing opposite the middle of the vulva and ending about one inch below the bottom of the bare area (Beveridge 1935a). The aim of this was to increase the area of bare skin around the vulva, remove any small folds in it, and render the adjacent wool more open (Beveridge 1935a). Scientific experiments also showed that the initial method removed insufficient skin to reduce the susceptibility of wrinkly animals to the same level as plain-bodied sheep (Graham *et al*. 1941, Johnstone and Graham 1941).

The initial procedure was modified (‘Modified Mules operation’) to a method in which two crescent-shaped pieces of woolled skin were cut from each side of the crutch (hindquarters) of Merino lambs (Beveridge 1984, Morley and Johnstone 1984). The cuts were started above the base of the tail and extended below the bare area, leaving wounds of up to five centimetres wide on opposite sides of the vulva of ewe lambs. This was to remove wool-bearing wrinkled skin, increase the perineal bare area and reduce the risk of breech strike throughout life (Beveridge 1984, Lee and Fisher 2007).

The importance of tail length in determining susceptibility to strike in unmulesed and modified mulesed sheep was recognized by Gill and Graham (1939). It was noted that butt-tailed or very short-tailed animals could not hold wool above the tail out of the way when defaecating or urinating and it was found that as the wool on the tip and sides of the tail grew longer it hung down into the urine steam, becoming stained and susceptible to strike (James 2006). Graham and Johnstone (1947) published an article in which they said that crutch strike had been virtually eliminated by the '*Modified Mules*' operation, but tail strike remained a problem.

In the late 1940s the '*Radical Mules*' was devised when the '*Modified Mules*' operation was adapted to involve the surgical removal of more skin from areas on the breech adjacent to the bare area around the uro-genital opening of ewes and the anus of castrated male sheep and from the dorsal surface of the tail to reduce tail strike (Graham and Johnstone 1947, Dun 1954, Luff 1976, Beveridge 1984, James 2006). The mulesing and tail stripping wounds were linked, leaving the tail completely free of wool (Luff 1976, Morley and Johnstone 1984, James 2006). The result of such removal is that during wound contraction and healing the existing bare areas on the breech and tail are stretched and permanently enlarged.

Watts and Perry (1975) and Morley *et al*. (1976), reported on the high incidences of breech strike associated with scouring in radically mulesed sheep with a very short tail. Furthermore, when dosed with purgative, both mulesed and unmulesed Merino lambs with shorter tails were also more strongly predisposed to flystrike (Watts and Marchant 1977, Watts and Luff 1978, Watts *et al*. 1979). It was also reported that radical mulesing with a short tail exposed the perineal skin and sensitive vulval and anal tissues to sunburn and was associated with an increased prevalence of rear end cancers (VandeGraaf 1976, Hawkins *et al*. 1981, Swan *et al*. 1984). A medium-long tail (docked to 3 joints or to the tip of the vulva) was recommended in radically mulesed sheep with diarrhoea and to provide protection of the sensitive vulval and anal areas against sunburn and cancer (Luff 1976).

In the 1970s the operation was further modified to the '*V- Mules*', which was the type of mulesing most commonly recommended until very recently (Yeo 1979 as cited by James 2006). The '*V – Mules*' is similar to the '*Radical Mules*' operation in that the tail and breech cuts join up, but a '*V*' of wool-bearing skin is left on top of the tail to provide protection against sunburn (James 2006).

Initially the operation in any form was not hailed with enthusiasm by the grazing community but was later adopted by some graziers in South Australia (Belschner 1953, Morley and Johnstone 1984). Many were repelled by the apparent cruelty and crudity of the surgery and others considered that it would militate against breeding for more resistant sheep (Belschner 1953, Morley and Johnstone 1984). However, the exceptional effectiveness of the '*Mules Operation*' has led it to be the keystone procedure in most integrated flystrike control programs (James 2006).

Efficacy and benefits of mulesing

In his article on the origin and early history of this practice, Beveridge (1984) describes the '*Mules Operation*' as '*one of the most important disease measures discovered in Australia'* and comments that *'many of the younger sheep men today do not fully appreciate what a severe problem blowfly strike was in the days before the Mules operation*'.

Mulesing is highly effective at reducing the incidence of breech strike (Johnstone and Graham 1941, Luff 1976, Watts *et al*. 1979, Morley and Johnstone 1984, Marchant 2003, Lee and Fisher 2007, Rothwell *et al*. 2007). Typically, the incidence of strike is reduced in Merino sheep from as high as 30 – 72 % for unmulesed sheep to 1% for mulesed, wrinkly sheep (Johnstone and Graham 1941, Morley and Johnstone 1984). In years of significant threat, the benefits of mulesing are much more pronounced (Lee and Fisher 2007). Mulesing is permanent and reduces the prevalence of breech strike from 60 - 80% in ewes to less than 1% when combined with crutching (Raadsma 1991a). In the early history of the sheep industry MacKerras (1937) reported that the value of the Mules operation lies in its effect on breech conformation. The operation also makes crutching easier (Luff 1976, Lee and Fisher 2007). Mulesing was also reported to reduce costs of controlling breech strike by a factor of three to four through improved reproduction of the breeding flock (easier mating, lambing), lower crutching costs (less frequent crutching), less wool lost as a result of breech strike; increased general productivity (Anson and Beasley 1975) and a higher market price at sale of sheep (Bryant and Watts 1983, Horton *et al*. 2002, Colditz 2006, Lee and Fisher 2007).

Mulesing was originally developed to protect wrinkly-breeched Merinos but also provided considerable benefits to non-Merinos and plain-breeched sheep (Richardson 1971, Luff 1976, Reid and Jones 1976, Lear and Faulkner 1977, Lottkowitz *et al*. 1984, Morley and Johnstone 1984). Benefits from mulesing Corriedales were indicated as early as 1947 (Graham *et al*. 1947). Richardson (1971) reported a reduction in strike incidence from 35.4% to 25% in mulesed Comeback ewes. Radically and modified-mulesed Corriedales and Border Leicester X Corriedale ewes sustained strike incidences of 3.8% (radical) and 19% (modified) in the Corriedales and 1.0% and 4.8% respectively in the crossbreds (Reid and Jones 1976). The increased area of bare perineal skin which renders sheep less liable to urine staining and dags (Johnstone and Graham 1941, Dun 1954, Reid and Jones 1976) is probably the major effect conferring protection to these breeds.

Moule (1948) indicated that selection for plain-breeched sheep alone was not sufficient to fully replicate the effectiveness of mulesing. The incidence of strike was 98% in unmulesed, wrinkly sheep, 19% in unmulesed 'plain-breeched' sheep and only 4% in mulesed sheep regardless of wrinkle status (Moule 1948). Thus the effectiveness of this surgical procedure led to the use of the Mules operation as a keystone procedure in integrated flystrike control programmes, specifically to control breech strike (James 2006).

One aspect that does deserve attention is that unmulesed sheep are reported anecdotally to be difficult to shear and crutch, and to suffer a greater number of shearing cuts with a greater severity around the breech area (Lee and Fisher 2007). Although there are no scientific data on this, it is possible that the welfare of unmulesed Merino sheep is compromised somewhat at shearing compared to that of mulesed animals (Lee and Fisher 2007). Another aspect to consider is the fact that fold removal is of advantage to the sheep because of the lessening of flystrike in the current generation, these advantages cannot be transferred to the next generation. Animals thus retain their inherent genetic capacity for producing lambs more or less wrinkled in the breech according to the original conformation of parents (Seddon 1935, Belschner 1953).

Welfare aspects of Mulesing

Until very recently it was argued that even though mulesing does cause pain (Belschner 1953, Fell and Shutt 1989), the long-term benefits in terms of fly control and reduced mortality from flystrike justify the procedure (Belschner 1953, Beveridge 1984, Colditz 2006, Plant 2006). Mulesing does reduce flystrike (Anderson *et al*. 1993), but at the cost of additional suffering since mulesing is performed without anaesthetics or analgesia (Townend 1987, Morris 2000).

Hormonal responses to the Mules operation were reported in 3 - 5 week-old lambs by Shutt *et al*. (1987). Metabolic responses, such as rise in free cortisol, following acute stress in sheep are well documented (Fell *et al*. 1985) and have diagnostic value as indicators of the relative effects of different stressors (Fell and Shutt 1986, 1988). Observations of post-operative behaviour in sheep, or behaviour during handling, have been correlated with hormone levels in some cases (Shutt *et al*. 1988), but not in others (Fell and Shutt 1988). The significance of ethological criteria for assessing stress and welfare in animals has been widely discussed (Wiepkema 1983, Blackshaw 1986, Sanford *et al*. 1986). Fell and Shutt (1989) later reported in more detail on the interaction between the behavioural, physiological and cognitive mechanisms (Burchfield 1985) of a stress response in 6 – 7 month-old weaners subjected to the Mules operation. The immediate rise in cortisol and *β*-endorphin after the Mules operation was similar to that reported previously in 3 – 5 week-old lambs (Shutt *et al*. 1987). Wolfle and Liebeskind (1983) reported that the supposed stimulation-produced analgesia associated with the increased plasma *β*-endorphin was quite apparent in the behaviour of the sheep for the first 1 – 2 h after the operation in the pen and on release into the paddock for grazing. Fell and Shutt (1989) reported that further peak levels of both hormones were found at the post-operation sampling in the 6 – 7 month-old weaners and that the stressor in this case was probably the handling of the animals in their post-operative condition. Mulesed lambs remembered the procedure and avoided the handler for 36 days afterwards (Fell and Shutt 1989). Combined with the behavioural data, this observation confirms a high degree of pain or stress. The stress response to mulesing can be further prolonged when the procedure is performed in older animals (Colditz 2006).

Although mulesing can reduce the incidence of flystrike around the breech, it has many drawbacks (Townend 1987). The wound bleeds freely and the lamb may die of shock. Cuts that are too deep can permanently cripple the animal (Townend 1987). The wounds may become infected (Graham 1990 as cited by Leipoldt 1996) and even when healed, the stretched skin remains sensitive to sunburn with frequent development of skin cancer (Townend 1987). Lambs that had been mulesed all demonstrated abnormal behaviour indicative of extreme pain 24 hours after mulesing and some were still in pain after 2 days (Morris 2000).

Alternative non-surgical methods or chemical mulesing

Alternative non-surgical methods (chemical mulesing) have been developed to enlarge the bare area on the breech. The earliest of those involved application to the skin of a caustic preparation that removed the wool and formed a scar that tightened the skin in the breech (the Manchester method) (Morley 1949, Belschner 1953, Colditz 2006, Rothwell *et al*. 2007). Welfare concerns regarding the levels of pain associated with this approach led to studies investigating the potential for a photoactive chemical (phenol or cresol) normally present in the body, to deplete wool follicles within the skin (Pratt and Hopkins 1976a, b, Colditz 2006, Rothwell *et al*. 2007). Chapman (1993) explored the use of cationic quaternary ammonium (QA) compounds that precipitate polyanionic glycosaminoglycans in the skin, causing necrosis. However, before any one of the latter two methods can be adopted, technical hurdles such as operator safety and sheep toxicity remain to be solved (Colditz 2006, Rothwell *et al*. 2007). Other methods such as ‘Freezing’ (Dolling *et al*. 1990), ‘High energy electrons (Sorrell *et al*. 1990)’, ‘5-amino levulinic acid and light’ and ‘Intra-dermal collagenase treatment’ were also developed (Rothwell *et al*. 2007) but unfortunately were not sufficiently developed for practical application. A plastic clip, acting much like the rubber rings used to castrate lambs, can be applied to wrinkles in the breech causing the excess skin to be shed, however, the impact of this procedure on the welfare of sheep must still be assessed (Colditz 2006).

Managerial methods

Strategic shearing and crutching (including dagging and pre-lamb crutching)

Time of shearing and crutching are the main management practices used to combat flystrike (Belschner 1953). It is a normal practice to shear sheep annually (SCARM 2001). Removal of wool from the sheep immediately reduces the susceptibility of the sheep to flystrike on any part of the body, mainly because it allows air and sunlight to get to the skin and dry out moist areas (Belschner 1953). MacLeod (1943b) identified wool length as the factor dominating sheep susceptibility to blowfly strike. Clipped sheep and young lambs with short fleeces (2 -3 month’s wool growth) are not usually struck, but as the length of the fleece increases so does the risk of contracting flystrike (French *et al*. 1996).

Crutching is the shearing of wool from the breech area (hindquarters) of sheep to keep the area dry and less susceptible to flystrike (McCulloch and Howe 1935, Belschner 1953, Marney *et al*. 1986, Bulletin No. 4128 1987, Scobie *et al*. 1999). This removes moist dags, wool stained with faeces and urine, and allows the underlying skin to dry out (Marney *et al*. 1986, Bulletin No. 4128 1987, Evans and Karlsson 2001a). Sometimes only the faecal contaminants or 'dags' are removed by a shearing procedure which is called 'dagging' in New Zealand. This is done prior to shearing, to keep contaminants out of the shearing facility (Scobie *et al*. 1999). French *et al*. (1992) reported 'dagging' or 'crutching' as a method for the control of blowfly strike in England and Wales.

Shearing and crutching is conducted at least once and commonly two to three times a year. In the Western Cape (South Africa) peak blowfly periods are early spring and late summer/autumn (Scholtz *et al*. 2000), therefore shearing prior to one of these periods and crutching prior to the other will minimize potential problems. Depending on the time of shearing, and considering that some sheep are shorn every 8 months in New Zealand, crutching may be done prior to mating or during periods of peak flystrike risk (Scobie *et al*. 1999). Lambing is also timed to start following either shearing or crutching to reduce breech strike associated with urine and afterbirth in long wool ewes (Belschner 1953, Wilson and Armstrong 2005). During high-risk periods shearing time can be altered to reduce sheep susceptibility, but the timing of shearing is usually determined by numerous other factors and thus has little flexibility (Horton *et al.* 2002). Furthermore, shearing sheep more than once per year would not be an economic or practical method of reducing flystrike in most instances.

'Pre-lamb crutching' is a specialized operation used to remove wool from around the breech and udder for reasons of general cleanliness (Belschner 1953, Scobie *et al*. 1999). This exposes the udder so that lambs can locate the teats more readily, cleans around the breech in case assistance is required during birth and reduces dag accumulation during lactation when the throughput of feed high in moisture content and susceptibility to gastro-intestinal parasites is increased.

Crutching and shearing were reported to have animal welfare implications (Scobie *et al*. 1997). Hargreaves and Hutson (1990a) claimed there was no difference in the stressfulness of partial versus complete shearing. They furthermore reported that up-ending (tipping the sheep over onto its rump) for shearing was, by itself, a stressful procedure (Hargreaves and Hutson 1990b).

Tail docking

Lydekker (1913) classified sheep breeds into groups based on tail length and morphology and indicated that most wild sheep have short tails. Length of tail is considered to be an index of degree of domestication, although the purpose and origin of this trait is unclear (Lydekker 1913, Shelton 1977, James *et al*. 1990). A long tail may lead to faecal soiling and urine staining and flystrike tends to be more prevalent in undocked lambs (Belschner 1953, French *et al*. 1994b, c, Vizard 1994, Scobie *et al*. 1999, Webb-Ware *et al*. 2000).

The amputation of lambs' tails to reduce dag accumulation and thereby reducing flystrike susceptibility is considered to be a regular part of animal husbandry and is used almost universally in countries producing woolled sheep (French *et al*. 1994b, c, Vizard 1994, Scobie *et al*. 1997, 1999, Scobie and O'Connell 2002, Fisher *et al*. 2004). It is a practice rooted in tradition, as it is considered necessary to prevent faecal soiling and flystrike and to improve the appearance of sheep (MAFF 1985 as cited by French *et al*. 1994a). In America most buyers of lambs pay less for lambs with an undocked tail because the tail is inedible and may have considerable weight (Battaglia 1998). Because of these reasons, tails on lambs are usually docked at a young age.

Numerous studies on lamb tail docking have been carried out, many with particular reference to the role of this practice in controlling flystrike (Joint Blowfly Committee 1933, 1940, Graham and Johnstone 1947, Graham *et al*. 1947, Watts and Marchant 1977, Watts and Luff 1978). Gill and Graham (1939) reported that sheep with shorter docked tails had significantly higher rates of flystrike. This was confirmed by Riches (1941, 1942) reporting that a medium length docked tail permanently reduced both breech and tail strike compared with shorter docked tails. Urine staining in ewes was also affected by tail length (Graham *et al*. 1947), with the lowest incidence of stained sheep noted in those with medium tails. Graham *et al*. (1947) reported a marked increase in dag formation with increasing tail length in Corriedales. Scientific literature recommended the combination of mulesing with tail-docking to the correct length, as highly successful in the control of breech strike (Seddon 1967, Luff 1976, Raadsma 1991a).

Normal tail docking practices in New Zealand tend to leave very short tail stumps or no tail stump at all (Scobie *et al*. 1999). Vizard (1994) however found that if the tail is docked too short, wool tends to hang over the anus and become soiled. At the other end of the range, the tail tends to become too heavy to lift as the sheep ages and if left undocked, the tail becomes fatter and more covered in wool (Scobie *et al*. 1999). Vizard (1994) recommended 'a 4-inch stump' as the most appropriate for Merino sheep. Scobie *et al*. (1999) furthermore reported that the characteristics of the wool of these breeds may play an important part. The wool of Merino and Perendale lambs is relatively short and has a fibre and staple architecture that makes the staples stand erect, whereas the wool on adult Coopworths and Romneys tends to hang down (Scobie *et al*. 1999). As the Perendale and Coopworth sheep used in their study grow older and carry a 12-month, adult fleece a curvilinear effect might become evident (Scobie *et al*. 1999).

Tails are removed without analgesia, using a knife, rubber elastrator ring or hot tail docking iron (Pollard *et al*. 2001). All tail-docking methods are known to cause distress and pain, with the knife generally considered to be the least desirable method (Shutt *et al*. 1987, Morris *et al*. 1994, Lester *et al*. 1996, Graham *et al*. 1997). Considerable effort has been spent investigating harm to the animal associated with tail removal (Molony and Kent 1997, Mellor and Stafford 2000). Mellor and Murray (1989) reported physiological and behavioural changes indicative of distress for up to 3 – 4 hours. Rhodes *et al*. (1989) also reported significant long and short term stress responses in lambs as a result of tail docking. The removal of the tail has the potential to affect many aspects of the animal's anatomy, physiology, behaviour, farm management, urine staining and consequent flystrike (Fisher *et al*. 2004).

Tail docking as a husbandry practice has also in recent years been challenged by animal welfare and animal rights groups as this practice is considered to be a 'painful mutilation' (Wood and Molony 1992). However, until an alternative can be found *'It is incumbent upon those responsible for sheep welfare to find the most humane practical method of docking, and to use it on lambs of an age when least pain or distress is caused'* Graham *et al*. (1997). Currently it is recommended in Australia and New Zealand that tail-docking should be performed on lambs as early as management practices will allow; preferably between two and twelve weeks (SCARM 2001). The Code of Practice furthermore recommends that the tail should be just long enough to cover the vulva in female sheep and should be of similar length in males (SCARM 2001). The 'Best Practice Reference Manual (BPRM) for wool sheep farming in South Africa (NWGA 2008/2009)' recommends that lambs should be docked before or up to 6 weeks of age regardless of the method used and that the tail stump must be left long enough to cover the external genitalia of ewe lambs and the anus of ram lambs.

Selective use of chemicals

Modern chemicals can be effective in controlling and preventing blowfly strike but the use of these products needs to be balanced against the fact that chemical residue in wool is a problem for wool processors (Russell 1994, Wilson and Armstrong 2005). It is therefore necessary to ensure that pesticide treatments result in minimal residues on wool while maintaining effective control of blowflies (Russell 1994, Jordan 2009). Surveys done in Australia have shown that many treatments applied less than six months before shearing are likely to leave unacceptable levels of pesticide residues on wool (Russell 1994, Jordan 2009). Pesticides start breaking down on the sheep's back from the time they are applied. However, some pesticide remains on the wool when the sheep is shorn and is then discharged into the environment as scour effluent or sludge upon processing (Jordan 2009).

Even when producers have used all management and husbandry options to their fullest, they are sometimes still confronted with specific blowfly problems that require treatment (Russell 1994). The effective use of pesticides according to label instructions and withholding periods when combined with IPM practices normally result in acceptable residue levels (Jordan 2009). Some general control principles suggested so that pesticide residues on wool are minimized at the next shearing include:

- *‘Treating with an effective pesticide as early as possible after shearing*
- *Minimizing the use of pesticides in the six months before shearing*
- *Avoiding the use of pesticides altogether in the three months before shearing*
- *Using the most effective and safest method of pesticide application*
- *Ensuring that equipment operates to the manufacturer’s specifications’* (Jordan 2009)

Strategic jetting involves treatment only if and when needed. Treating individual flystruck sheep is preferable to treating entire mobs because it minimizes pesticide residues across the whole clip (Evans and Karlsson 2001a, Jordan 2009). Acceptable residue levels can also be achieved by applying preventative jetting, back lining or spray-on if required for some mobs (Evans and Karlsson 2001a). The key to effective jetting is the depth of penetration by the pesticide into the wool.

Pesticides from the Insect Growth Regulator (IGR) or Spinosyn groups are recommended (Jordan 2009). Spinosad (a new natural product registered as Extinosad®) has very low mammalian toxicity, is safe for shearers and operators and is relatively safe to the environment (Crouse and Sparks 1998). This product breaks down quickly in the wool (Russell *et al*. 2000) leading to low wool residues but a briefer protection period against re-infestation than more persistent molecules. This characteristic makes it very useful for the treatment of sheep with long wool where other products leave unacceptable wool residues at shearing time (Rothwell *et al*. 2001). This product is thus extremely useful when used tactically in the face of a fly wave in long wool sheep.

Paddock/environment management

- ***Pasture management – internal parasites***

  Helminth infestation can predispose sheep to breech strike because of the accumulation of dags in the breech. Grazing management procedures to control helminth infection in sheep are therefore often seen as preventative, evasive or diluting (Barger 1997). Pasture management should be used as a primary tool to control internal parasites. Sheep ingest infective parasite larvae from pasture. The rate at which they are ingested can be controlled through pasture management. Worm larvae are seldom found higher than 50 mm above ground level. Preventing animals from grazing below this height reduces the number of worm larvae ingested (Hale 2006). Animals that eat closer to the ground tend to have more problems with internal parasites. Management involves the monitoring of animals as well as the pasture. Allowing animals to graze pastures too short results in more parasite larva being consumed as well as a reduced feed intake, therefore harming the animal in two ways. It also inhibits pasture regrowth. Larvae migrate no more than ~30 cm from a manure pile. Livestock not forced to eat close to their own manure will thus consume fewer larvae. Providing areas where animals can browse (eat brush, shrubs, small tress, etc.) and eat higher above ground level helps to control internal parasite problems.

Reducing the stocking rate decreases the quantity of worms spread on a pasture (Coffey *et al*. 2007). The more animals you have on one pasture, the more densely the worms will be deposited. Animals on densely stocked pastures are thus more likely to have parasite problems. Cattle do not share the same internal parasites as sheep and goats. Cattle consume sheep and goat parasite larvae, which helps "clean" the pasture for the small ruminants.

- ***Pasture management – blowfly strike***

  Flystrike risk is determined by a combination of the fly population, the number of susceptible (moist, protein rich sites) sheep and the suitability of the environment (maximum daily temperature must be 17°C or greater; average wind speed range must be less than 30km/hr) (Monzu and Mangano 1986a, Horton *et al*. 2001). Strike flies need sources of sugar, protein and water to survive and breed. On a farm these are generally found in areas of bush or scrub, often in gullies where carrion may be overlooked. Gullies also provide shelter for flies which can't fly in excessively windy conditions. High risk mobs (such as weaners) can be identified, and prevented from grazing high risk paddocks such as low lying areas not exposed to the elements. At times when sheep are likely to be susceptible to flystrike, they should be grazed in open country, and if possible, at lower than the usual stocking rate. Where circumstances and topography allow, sheep should be grazed on higher ground and exposed to maximum wind flow when prone to flystrike, as fly activity is reduced with wind speed (Heath 1994). Heavy concentrations of sheep and prolonged grazing in one paddock intensify the odours attractive to flies and may increase the risk of flystrike (Heath 1994).

- ***The utilization of specialist forages***

  The link between dags and flystrike (Miller 1939) is well known and is consistent with a high proportion of strikes in young sheep in the hindquarter and perineal regions (Heath and Bishop 1995). Grazing sheep on pasture species that reduce dags or the moisture content of faeces has already been shown to assist in reducing flystrike prevalence (Leathwick and Atkinson 1995, 1996; Leathwick and Heath 2001). Numerous studies have demonstrated the ability of plants containing condensed tannins (CT) to reduce dag formation in sheep (Robertson *et al.* 1995; Niezen *et al.* 1998).

  A number of trials have assessed the potential of pasture species containing condensed tannins to enhance animal performance (Wang *et al*. 1994) and to reduce the detrimental effects of gastrointestinal nematode parasites (Waghorn and Shelton 1992, Niezen *et al*. 1993, 1994). The effects appear quite pronounced on forages containing condensed tannins such as birdsfoot trefoil (*Lotus corniculatus*) and sulla (*Hedysarum coronarium*) (Niezen *et al*. 1993, 1995, 1998). Tannin-rich forages, such as *Sericea lespedeza*, have also been shown to help reduce internal parasite egg counts (Min and Hart 2003; Shaik *et al*. 2004; Van Rooyen 2008).

An incidental finding from some of these trials has been a reduction in faecal moisture content, dag formation and an apparent decrease in flystrike associated with the grazing of tannin containing pastures (Niezen *et al*. 1995).

- ***Nutritional management***

  High levels of endophyte in perennial ryegrass have been demonstrated to cause a marked increase in the prevalence of diarrhoea, dag formation and breech strike in lambs (Fletcher and Sutherland 1993 as cited by Larsen *et al*. 1994). The amount or quality of pastures is also likely to be a risk factor. Watts *et al*. (1978) found the occurrence of diarrhoea in ewes grazing long pastures was at least double that of ewes grazing short pasture. Davidson *et al*. (2006) reported a significant reduction in dag scores in sheep that were fed a supplement high in fibre content compared to sheep on pasture only. Grazing management can thus contribute to a reduction in dag formation in unmulesed weaners (Horton and Iles 2007).

Population control methods

Suppression of blowfly populations has focused on fly traps and genetic control. Foster *et al*. (1975) reported that flies released as pupae within a favourable habitat spread on average only 1.2 km in 48 hours and 1.6 km in 9 days after emergence, however most flies remained within a 1km radius of the emergence site. The results from a study by Gleeson and Heath (1997) provided evidence that in New Zealand *L. cuprina* is restricted to sheep farms and within these is predominantly found in the presence of sheep. It is thus assumed that blowflies have a low tendency for dispersal when favourable habitat conditions exist. It was furthermore reported that one of the major contributors to fly migration between regions is the movement of infested sheep rather than movement of the flies themselves (Gleeson and Heath 1997). Localized control measures such as large-scale trapping and genetic control techniques therefore have potential for controlling *L. cuprina* numbers while reducing reliance on insecticide use (Gleeson and Heath 1997).

Trapping of blowflies

Fly traps have been used in the Australian sheep industry for many years (Newman and Clarke 1926, MacKerras 1936, Vogt and Havenstein 1974, Vogt *et al*. 1983, 1985a, b, Anderson *et al*. 1990, Dymock and Forgie 1995, Ward and Farrell 2000). Numerous modifications of the 'West-Australian' flytrap - first described by Newman and Clark (1926) - have been made over the years. MacKerras *et al.* (1936) described a bait bin, based on liver and sodium sulfide that reduced blowfly strike by up to 50%. Carrion-baited traps have been used in many studies to sample field populations (Vogt *et al.* 1985a, Dymock and Forgie 1995). This general approach was still used in the 1980's (Vogt *et al*. 1983, 1985b). Even though these traps apparently reduced flystrike, a constraint to their use was the amount of labour needed to regularly service the traps (Ward and Farrell 2000) and trapping was considered not to be cost effective (Levot 2009).

The discovery of the Australian sheep blowfly *L. cuprina* in New Zealand in 1989 resulted in renewed studies on blowfly ecology and prompted investigations into finding a cheap substitute for the no longer available commercial model of trap. However, the circular plastic food containers used as chambers in these traps provided the basis of an idea for a static trap developed by Cole (1996). In New Zealand a commercially produced cylindrical galvanised iron version had been used since the 1960s but a detailed description had not been published (Cole 1996). Wind-oriented traps designed in Australia by Vogt *et al*. (1985a) were used in New Zealand for two seasons to study the effects of variables such as height of trap, duration, and timing of trapping on the blowfly species composition that was collected (Dymock *et al*. 1990, 1991). However the wind-oriented trap proved to be unsuitable for New Zealand conditions and was expensive to manufacture (Cole 1996). Cole described a further modification of the West Australian fly trap; a trap made from polyethylene terephthalate (PET) soft drink bottles developed to be used as a research tool. However, an even simpler and cheaper trap design 'FLYtrack' has been developed since (Cole *et al*. 1993).

The control of populations of pest insect species using non-return traps and targets, usually accompanied by semiochemical baits, has been considered widely (Broce *et al*. 1977, Coppedge *et al*. 1978, Haniotakis *et al*. 1986). In the early 1990s, a synthetic lure (Lucilure®) was developed to specifically attract *L. cuprina* (Urech *et al*. 1993) and in 1994 the insecticide-free trapping system, the Lucitrap® [1](Miazma, Pty. Ltd. Mt. Crosby, Queensland, 4306, 1994), utilizing this lure, was released in Australia (Anonymous, 1994). The Lucitrap® system is considered as a selective trapping system for the Australian sheep blowfly, *L. cuprina* (Urech *et al*. 1993, 1996, 2001, Scholtz *et al*. 2000, 2001a, b), and has been commercially available since 1995.

Trapping blowflies using the Lucitrap® system has proved very effective by virtue of its design. The attractant works by mimicking fleece rot, animal carcasses, urine and faeces, and although blowflies are unlikely to escape the trap once entered, other flies can do so more easily (Urech *et al*. 2001, Armstrong *et al*. 2005). Urech *et al*. (1996) and Ward and Farrell (2000) reported the synthetic lures used in this system to be more attractive to *L. cuprina* than the carrion and sodium sulfide baits previously used by Dymock and Forgie (1995). Ward and Farrell (2000) also reported the Lucitrap® system, unlike bait bins, required minimal ongoing labour input. Improvements to the Lucitrap®, by increasing the shelf life of Lucilure® from four months to at least two years and by making use of a more transparent bucket, also made it a more attractive component for inclusion in an Integrated Pest Management control strategy for sheep blowflies (Urech *et al*. 2001).

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[*] Initially manufactured by Miazma, currently manufactured by Bioglobal Ltd, 226 Grindle Road, Wacol, Queensland, 4076

Urech *et al*. (1996) demonstrated the effectiveness of the Lucitrap® system in reducing blowfly populations in the field at two Queensland localities. The study was extended to cover 21 trials in five Australian states over three summers (Urech *et al*. 1998). Suppression of the blowfly population, amounting on average to 77%, was achieved in 62% of these trials. No conclusion could be drawn in 24% of the trials, owing to very low fly counts during very dry conditions. In South Africa Lucitrap® has also been shown to reduce the populations of *L. cuprina* when used at 1 trap per 100 sheep (Scholtz *et al*. 2000, 2001a, b).

Traps were most effective in sites near water, exposed to the sun, sheltered from the wind and attached to posts rather than to trees (Horton *et al*. 2001). Furthermore, it is of utmost importance that producers maintain the Lucitraps® at maximum efficiency (Horton *et al*. 2001). Reports from early users of the Lucitrap® had suggested that the number of flies declined over several years while the traps where in use; however, results obtained by Horton *et al.* (2001) suggested that the traps simply might have become less efficient over time.

An important factor to consider in monitoring fly populations is how the numbers of the flies caught relate to incidence in flystrike in sheep flocks (Cottam *et al.* 1998). Ward and Farrell (2001) reported a 46% reduction in strike rate in a trial conducted in southern Queensland by using the Lucitrap® system. Wardhaugh and Morton (1990) reported that the incidence of flystrike was related to the log density of gravid females in the area during the previous week. As a result of the log relationship, reduction of fly numbers by 70% would be necessary to reduce flystrike by 50% (Wardhaugh and Morton 1990). To be effective with respect to reduction of on-farm costs a much greater reduction in flystrike would be necessary and it is likely that the traps would need to capture more than 90% of the available flies (Wardhaugh and Morton 1990). Scientific literature reported that intensive use of Lucitrap® (Ward and Farrell 2001) and a high level of fly-trapping for several years may reduce blowflies to more manageable levels but are unlikely to prevent all cases of flystrike (Heath 1994, Evans and Karlsson 2010).

The value of trap catches as indicators of population trends is questionable; the main limitation being that differences in weather conditions can alter trap catches independently of changes in the population density (Whitten *et al*. 1977). Data on fly abundance, flock management and weather conditions are not only a prerequisite for rationalizing insecticide usage, but are also essential for assessing the potential benefits of alternative control strategies based on fly suppression (Wardhaugh and Morton, 1990). Furthermore the large numbers of adult females that need to be attracted by traps to achieve effective population management (Broughan and Wall 2006) and to allow reduction of pesticide treatment (Horton *et al*. 2001) is seldom achievable.

As a result traps or targets are usually only used as monitoring tools for most pest insect populations (Heath 1994, Ward and Farrell 2000, Broughan and Wall 2006); for ecological studies and in a few cases for population control. One notable exception to this is the tsetse fly, *Glossina* spp. (Vale *et al*. 1986), where the high level of control that can be achieved is due in large part to their very low inherent rate of reproduction and the availability of highly effective baits and traps (Broughan and Wall 2006).

In the early days, Smit (1928) was of the opinion '*that the trapping of blowflies must be a supplementary measure, since even though substantial numbers of flies may be caught in traps the numbers caught in a trap does not always indicate the amount of good the trap is doing'.* Heath (1994) reported that the Lucitrap® may be used as an 'early warning' system to detect the emergence of blowflies and to decide when treatment is needed, but strikes can occur even when there is a low population of flies. The Lucitrap® system is therefore most effective when used in combination with other management systems to keep flystrike at a low level (Evans and Karlsson 2010).

SIRM (Sterile Insect Release Method)

Alternative methods of control that have been investigated in Australia, include the eradication of the major primary strike species, *L. cuprina*, using genetic control (Whitten *et al.* 1977, Mahon 2001). In a SIRM control program the males are irradiated or chemo-sterilised and such a control program relies on the fact that female flies mate only once in their life-time. A SIRM control program is based on the inundative release of sterile flies (Horton *et al*. 2002). SIRM has been used successfully in several large-scale eradication programmes, notably the New World screwworm fly (Wyss 2002) in North and Central America, and in various species of fruit flies.

The distribution of *L. cuprina* in Australia is closely associated with areas devoted to sheep grazing and in some regions; its status is effectively that of an obligate parasite (Anderson *et al*. 1984, 1988). However, the presence of persistent populations of *L. cuprina* around Darwin and elsewhere in Australia (Norris 1990) indicate that the species can subsist, albeit in small numbers, in the absence of sheep over a very wide range of environmental conditions. In Tasmania, possum carcasses have been shown to support limited breeding by *L. cuprina* (Lang *et al*. 2001) and it is certain that other large dead animals will be similarly exploited. For this reason, any attempt to eradicate the pest from sheep grazing areas of Tasmania will require the release of sterile flies over the entire island. Irradiation or chemo-sterilisation of males is considered biologically feasible but uneconomical for the control of the sheep blowfly (Johnson 1998).

With the general acceptance that the eradication of *L. cuprina* by either large-scale trapping or by the sterile insect technique is not feasible, there is an ongoing need to reduce the risk of animals being struck (Colditz *et al*. 2006).

Other methods

Vaccination

Vaccination against larval infection (O'Donnell *et al.* 1980, 1981) and vaccination against fleece conditions that predispose sheep to strike has been investigated (Sandeman *et al.* 1985, Sandeman *et al.* 1986, Sandeman 1990). Many attempts to develop vaccines to control flystrike were made, primarily directed against *L. cuprina* and against *Pseudomonas aeruginosa* (Sandeman 1990, Burrell *et al*. 1992, Colditz *et al*. 2006). The *Pseudomonas* vaccines gave good results in some flocks, but were not effective in others, because there are also other causes of fleece rot in sheep that will predispose them to body strike. Attempts to develop an effective vaccine against blowfly larvae have been unsuccessful over some decades (Colditz *et al*. 2006), and only new technology could be expected to re-establish this method of flystrike control as a likely option (Bell and Sackett 2005).

Selective breeding

'Mulesing is an admission by sheep breeders that their animals do not possess the breeding required for survival in their area'. (People for the Ethical Treatment of Animals 2004 - Roger Meischke).

'Mulesing is the surgical correction of a genetic fault in the Australian Merino flock' - (Townend 1987).

Introduction

A long term goal in the management of blowfly strike in sheep has to be the permanent reduction of susceptibility to strike through genetic selection. Selection could be used independently or as part of an IPM program.

Although resistance to blowfly strike is expressed as an 'all-or-none' trait (i.e. the animal is either struck or not struck) it is highly likely that genetic resistance is contributed to by variation in a number of different genes which control fleece, skin and immune system characteristics (Raadsma 1987). It is the net effect of all these genes which make up resistance and which are suitable for exploitation through selective breeding. Falconer (1965) described a model for disease resistance, where the result of all the factors influencing the relative susceptibility of animals resembles an underlying normal distribution. The animal will develop symptoms of the disease when a threshold level has been reached, whereas unaffected animals are below the threshold and are relatively less susceptible (Raadsma 1987).

When blowfly strike became a widespread problem in Australia early in the 20th Century, it was recognised that body conformation (Belschner 1937b), wrinkle score (Seddon 1931, Seddon *et al*. 1931, Seddon and Belschner 1937) and wool characteristics (Joint Blowfly 1933, 1940) all influence susceptibility to blowfly strike. Breeding sheep with reduced susceptibility was one of the earliest approaches to flystrike control and has continued to be an element of most breeding programs (Joint Blowfly Committee 1933, 1940, Belschner 1937b, Atkins and McGuirk 1979, Archer *et al*. 1982, Raadsma and Rogan 1987, Raadsma 1991b, c, Scobie *et al*. 1999, 2007, Mortimer 2001a, b, Murray *et a*l. 2007, Edwards *et al*. 2009, Greeff and Karlsson 2009, Hatcher *et al*. 2009, Smith *et al*. 2009a,b). More than half a century ago, Turpin (1947) was of the opinion that blowfly strike in the breech could be considerably reduced in South Africa, if sheep were selected with a view of eliminating susceptible crutches. Mulesing, however, was exceptionally effective in controlling breech strike; so much so, that most of the breeding efforts have concentrated on breeding animals resistant to body strike rather than breeding animals resistant to breech strike (Dunlop and Hayman 1958, Atkins and McGuirk 1976, 1979, Atkins *et al*. 1980, Raadsma 1987, 1991a, b, c, Raadsma and Wilkinson 1990, Raadsma *et al*. 1989, Mortimer *et al*. 1998). Genetic solutions for breech strike have actually not been widely adopted for the following reasons:

- The effectiveness of mulesing in controlling breech strike
- Selecting for ‘plain-breeched’ sheep only is not sufficient to fully replicate the effectiveness of mulesing
- The low prevalence of Merino sheep with breech characteristics that render the animals truly resistant to strike also complicated the pursuit of this objective (Edwards *et al*. 2009).

Of the alternatives to the surgical mulesing operation, a genetic solution is the most attractive for breech strike because, unlike most of the physical and chemical interventions available to date and under development, it is painless (Edwards *et al*. 2009). Animals which are genetically resistant to flystrike will require less labour (Archer *et al*. 1982, James 2006) and less chemical pesticide (James 2006).

Direct selection

To identify sheep that are genetically resistant to an organism the sheep must be exposed to the organism in a natural state to allow the organism to challenge the sheep (Raadsma 1987, Greeff and Karlsson 2005). The response to selection is highest if a trait is selected for directly (Raadsma 1987, Raadsma *et al*. 1987b, Raadsma and Rogan 1987). However, selecting directly for blowfly strike resistance is often not efficient because of the sporadic nature of the disease and the associated production losses (Raadsma *et al*. 1987b, Greeff and Karlsson 2005). A further limiting factor is the fact that nearly all Merinos are treated by some preventative measure (e.g. crutched; jetted; mulesed) whereby they are protected from becoming infected (Greeff and Karlsson 2005). A challenge based selection method can potentially become very labor intensive to manage if it is to avoid serious animal welfare issues (Karlsson *et al*. 2008).

Indirect selection

The alternative is to identify those characteristics that make a sheep susceptible (indicator traits) and then select for or against them (Raadsma 1987, Greeff and Karlsson 2005). Fleece rot and dermatophilosis are the two main conditions that predispose sheep to body strike (Belschner 1937a, Raadsma 1987, Horton 1999). The traits that predispose sheep to breech strike are the number of caudal folds in the breech area, the clean area around the anus and vagina, resistance to gastro-intestinal nematodes, susceptibility to diarrhoea (dags) and to a lesser extent fleece rot, dermo, high suint, wool colour, fleece moisture and smell/odour (Greeff and Karlsson 2005, James 2006, Leary 2006, Murray *et al*. 2007, Karlsson *et al*. 2008). Too successfully breed sheep that are resistant to strike there are three things to consider, namely:

- the trait must be measurable;
- there must be variation in the trait and
- the trait must be heritable (McGuirk and Atkins 1980, Pascoe 1982, Greeff and Karlsson 2005).

Resistance to body strike

Indicator trait - Fleece rot and Dermatophilosis

The susceptibility of sheep to fleece rot and dermatophilosis as possible indicator traits for body strike has been investigated intensively (McGuirk and Atkins 1980, 1984, Raadsma 1989, Raadsma 1991a, b, c, Raadsma *et al*. 1988, 1989, Raadsma *et al*. 1997). Raadsma and Rogan (1987) reported that susceptibility to fleece rot or dermatophilosis is genetically correlated with body strike. In the case of fleece rot, Atkins and McGuirk (1979) have consistently calculated a near-unity genetic correlation between fleece rot incidence and the incidence or severity of body strike. From a breeding point of view, the two diseases can therefore be considered as the same disease entity, so that a reduction in fleece rot susceptibility through breeding should result in a concomitant reduction in genetic susceptibility to body strike (Raadsma and Rogan 1987). To estimate the potential for genetic improvement in body strike resistance through within-flock selection it was considered essential to estimate the magnitude of the genetic variation in resistance – the heritability (Raadsma and Rogan 1987).

For traits like body strike, fleece rot and dermatophilosis incidence, which are binomially distributed, the heritability estimate is expected to be dependent on the mean incidence of the condition in the population (Dempster and Lerner 1950, Hill and Smith 1977). However, the dependence of the heritability estimate on the incidence of the condition complicates comparisons of heritability estimates in different populations, and the prediction of responses to selection.

The estimation of the heritability of susceptibility to fleece rot and body strike independent of incidence is possible when we consider an animal's liability to disease. Liability to fleece rot and body strike is defined as the sum total of the genetic and environmental factors influencing an animal's susceptibility to these diseases (Falconer 1965). While expression of a character at the phenotypic level may be in an all-or-none fashion, the underlying liability to the condition is assumed to be normally distributed. The animals with a liability exceeding a certain threshold will become affected, whereas animals below the threshold will remain unaffected. Variation in liability not only expresses the individual's innate tendency to develop or contract the disease, but also combines external circumstances which render the animal more or less likely to develop the disease (Raadsma and Rogan 1987). The problem with that is that the inherent susceptibility of individual sheep or flocks of sheep is not expressed until the challenge conditions are such that at least some of the animals pass the threshold and become affected with fleece rot, body strike or dermatophilosis (Raadsma 1987).

Heritability estimates for fleece rot incidence derived by McGuirk and Atkins (1984) support the expectation that heritability will be highest at incidences near 0.5. Genetic variation for the predisposition of sheep to fleece rot and its more serious sequel, body strike, is reflected in a moderate to high (0.3 – 0.4) heritability of liability to these diseases (Raadsma 1991b). Falconer (1965) proposed that heritability on the liability scale could be estimated from the incidences of the condition in the general population and among relatives. Estimates of the heritability of liability have been based on analyses of parent-offspring regressions (McGuirk and Atkins 1984, Thompson *et al*. 1985) or half-sib designs (McGuirk and Atkins 1984, Raadsma *et al*. 1989, Raadsma 1991c). Furthermore the ability to alter the susceptibility of sheep has been demonstrated in divergent lines selected for increased (Susceptible line) and reduced (Resistant line) expression of body strike and fleece rot (McGuirk *et al.* 1978). Differences between the lines in fleece rot and body strike incidences were observed in both a low risk environment (Raadsma 1991a) and in a high risk environment (Raadsma 1991b). Knowledge on genetic variation in resistance to body strike both within and between flocks is well established (Atkins and McGuirk 1976, 1979, Raadsma *et al*. 1992). Bloodline and strain differences in susceptibility to flystrike and fleece rot readily occurs in Australia (Raadsma *et al*. 1989, Raadsma *et al*. 1997), leaving producers the option of bloodline substitution. It is therefore accepted that Merino sheep can be selected against susceptibility to fleece rot and body strike, even in high rainfall areas (Raadsma 1991a, b). Evans and Karlsson (2010) identified selective breeding and culling for fleece rot, dermatophilosis and flystrike as the most effective long-term options in a self-replacing flock. A long-term strategy to reduce blowfly strike in sheep is selection for reduced susceptibility to blowfly strike and fleece rot, a superficial bacterial dermatitis and major precursor of body strike (Mortimer *et al*. 1998).

Resistance to breech strike

Breech strike is a complex trait which strongly depends on environmental factors such as the presence of blowflies and whether the wool in the breech is moist and/or soiled. Predisposition to breech strike is likely to depend on a complex of traits including degree of skin wrinkle, wool cover over the breech and crutch (Edwards *et al*. 2009), the architecture and composition of the wool surrounding the breech and crutch, susceptibility to scouring (nutrition- and worm-induced), and anatomical and behavioural traits associated with urination (see review by James 2006).

Indicator trait - number of caudal folds in the breech area

Prior to the development of the Mules operation, investigations were carried out to identify types of sheep which were susceptible to breech strike. The major predisposing factor was found to be the number and location of caudal folds in the breech area (Seddon 1931, Seddon *et al*. 1931, Seddon and Belschner 1937). Seddon *et al*. (1931) categorised 1000 unmulesed Merino ewes into plain (A-type), intermediate (B-type) and wrinkled (C-type) type sheep according to the amount of wrinkles (Fig. 3a, b). The plain-bodied ewes were much less susceptible to flystrike whereas the wrinkled type ewes were highly susceptible to flystrike (Seddon *et al*. 1931, Joint Blowfly Committee 1933, MacKerras 1936, Belschner 1953). This difference is well illustrated in Fig. 4. Seddon *et al*. (1931) furthermore observed that matings from rams and ewes of the same susceptibility class predominantly produced offspring of the same class. From South Africa it was reported that blowfly strike in the breech could be considerably reduced, if sheep were selected to eliminate susceptible crutches (De Vries and De Klerk 1943, 1944, Turpin 1947).

One method of reducing blowfly strike is to render the host animal less susceptible, and the breeding of plain-bodied sheep has been advocated (Seddon *et al*. 1931, Belschner 1953, Turner 1977). The widespread practice of mulesing and computing difficulties in calculating (co)variance ratios involving traits assessed on the binomial scale have probably hampered attempts to find a genetic solution. However, software to allow the estimation of heritability and genetic correlations involving binomial and/or threshold traits and normally distributed traits are now readily available (Misztal *et al*. 2002, Misztal 2008).

Most heritability estimates for wrinkle score have been determined by using the photographic standards of Carter (1943) or Turner *et al*. (1953). These standards contain photographs of the neck, sides and breech of a variety of animals, each conforming to a specific wrinkle score. Wrinkle scores are assigned separately for the different body regions and then totalled to give the final score. In cases where Merinos were mulesed the breech wrinkle scores were sometimes omitted. James (2006) reviewed the available heritability estimates for wrinkle scores for different breeds.

For the purpose of this study reference will be made to the different wrinkle scores for Merinos. Terrill and Hazel (1943, 1946) and Jones *et al*. (1946) found wrinkles to be moderately heritable (h^2 = 0.32 and 0.39, h^2 = 0.45; respectively). More recent estimates by Smith *et al*. (2009a) and Mortimer *et al*. (2009) reported comparable heritability estimates of h^2 = 0.25 and h^2 = 0.42 for body wrinkle score, respectively. Lewer *et al*. (1995) reported a somewhat lower heritability estimate of 0.15 for body wrinkle score and a moderately high heritability estimate of 0.27 for neck wrinkle score. Few h^2 estimates specifically for breech wrinkle score are available in the literature. Lewer *et al*. (1995) estimated h^2 at 0.19 for breech wrinkle score, while Raadsma and Rogan (1987) cited a range of h^2 estimates of 0.4 - 0.5 with the source given as McGuirk (unpublished data). More recent h^2 estimates for breech wrinkle score were 0.45 (Greeff and Karlsson 2009) and 0.36 (Smith *et al*. 2009a).

Studies done by Jackson and James (1970) and Lewer *et al*. (1995) reported estimates of 1.00 and 0.91 for the genetic correlation between wrinkles scored on the neck and on the breech. A high genetic correlation of 0.99 between body and breech wrinkle was accordingly reported by Jackson and James (1970). Lewer *et al*. (1995) however, reported a somewhat lower genetic correlation of 0.50. In a more recent study by Mortimer *et al*. (2009) a very high positive genetic correlation of 0.92 between neck wrinkle score and body wrinkle score was reported. This estimate is consistent with earlier estimates exceeding 0.90 (Beattie 1962, Mortimer and Atkins 1993, Lewer *et al*. 1995). The very high positive genetic correlations between neck wrinkle score and body wrinkle score; as well as moderate to high heritability estimates on the respective body regions, indicates that substantial gain could be made by purposeful selection for less wrinkled sheep. This is in accordance with the review of Turner (1977), which suggested that, with the high h^2 of wrinkle score, genetic change towards plainer–bodied animals should be easy to achieve.

Indicator trait - Bare area

De Vries and De Klerk 1944 recommended that '*the bare patch in the locality of the anus and vulva should be as large as possible*' (De Vries and De Klerk 1944). Belschner (1953) was of the opinion that it is very important, from a flystrike control and general hygiene perspective, that the anus, vulva and udder of ewes and the anus and pizzle of rams and wethers be surrounded by areas which are completely free of wool growth. VandeGraaf (1976) cautioned that extensive areas of bare skin may be undesirable as it may predispose animals to sunburn, particularly when combined with a short tail docking. A naturally woolless but hairy pubic area may thus be superior to the effect produced by either surgical or chemical mulesing (Pratt and Hopkins 1976a, b). It is the wool around the anus that is the root cause of the problem as it predisposes the animal to the formation of dags which could attract flystrike. However, the underlying cause of flystrike is not the dags *per se*, as animals without any dags can also be struck (Scobie *et al*. 2002).

Thatcher and Pascoe (1973) presented a photograph of a Wiltshire Horn X Romney Marsh sheep with a bare breech and suggested that this would be a valuable trait as it would eliminate the need for crutching, mulesing and jetting to control breech strike. Both the East Friesian and Wiltshire Horn breeds have relatively large natural bare areas (Scobie *et al*. 1999). Scobie *et al*. (1997, 1999) furthermore reported that there are individual sheep with 'usefully bare breeches' found within some breeds, notably the Border Leicester, Poll Dorset, East Friesian and Texel breeds. Scobie *et al*. (1997) proposed a breeding goal based on traits that would minimize or eliminate the need for animal husbandry practices like tail docking, mulesing, eye-clipping, crutching and dagging.

In addition to the relatively large bare area of skin around the perineum, the Wiltshire Horn breed also sheds its fleece annually (Scobie *et al*. 1999). Tierney (1978) crossed Merinos with Wiltshire Horn sheep in an attempt to incorporate some of these fleece-shedding characteristics into Merino sheep and so produce an ‘easy-care’ self-crutching type of sheep. Tierney (1978) showed a dramatic reduction in flystrike of the breech in Wiltshire Horn X Merino sheep in comparison with Merinos. In later years Rathie *et al*. (1994) confirmed Tierney’s findings by reporting that Wiltshire Horn X Merino ewes were less susceptible to flystrike than Merinos sheep that were both crutched and mulesed. Rathie *et al*. (1994) furthermore reported that the proportion of flystruck sheep increased as the proportion of Merino genes increased in subsequent crosses; suggesting a genetic pre-disposition to breech strike in Merinos. Litherland *et al*. (1992) found Wiltshire Horn lambs less susceptible to blowfly strike than Merinos in New Zealand. However the studies by Rathie *et al*. (1994), Litherland *et al.* (1992), Scobie *et al*. (1999) and Scobie *et al*. (2002) on different breeds of sheep (Coopworth, Wiltshire Horns, Perendale and Dorset) included breeds generally not high in wool production and often bare in regions such as the belly and head (Hebart *et al*. 2006). James (2006) was of the opinion that, since no measurements were taken of the size of the perineal region in these studies, the degree to which reduced susceptibility to flystrike could be attributed to a larger bare area or to shedding of the breech wool is uncertain.

In two studies where the main predisposing factor was diarrhoea, significantly more wethers (49% and 27% respectively) than ewes (25% and 13% respectively) were struck (Morley *et al*. 1976, Watts and Luff 1978). Watts and Luff (1978) reported bare areas of 7.0 cm in length and 4.5 cm in width for ewes. Comparable figures for wethers were respectively 6.0 cm and 3.7 cm. In a study on different breed and crossbred lambs in New Zealand, Scobie *et al*. (2002) found that the relative risk of flystrike in the breech varied between crossbred females and males under seasonally changing conditions. Scobie *et al*. (2002) scored the area of bare skin from 1 (little or no bare perineal skin) to 5 (largest bare area), in groups of sheep from a variety of breed backgrounds. Breed types included in this study were Perendale, Finnish Landrace X Romney, Finnish Landrace X Dorset Down and 3 composite breeds, 1 based on crosses of Finnish Landrace X Cheviot, 1 based on the Wiltshire and the other based on a feral X Merino sheep (Scobie *et al*. 2002). French *et al*. (1998) and Scobie *et al.* (1999, 2007) reported that male lambs are more likely to develop dags than females as a consequence of the larger bare area caused by external female genitalia. It is well-known that males generally have smaller bare areas than females, but in most cases it is hard to draw conclusions about the effects of this difference on susceptibility to strike because of the complicating effects of urine-staining in females (James 2006). Scobie *et al*. (2007) was of the conviction that greater bareness should afford greater protection against breech strike in both sexes.

Breech bareness score at weaning has been shown to be heritable and negatively correlated with dag score in composite sheep selected for short tails and bareness of the breech and belly (Scobie *et al.* 2007, 2008). The possibility thus exists that genes from other breeds could be introduced to increase bare area dimensions in Merinos (James 2006). However, crossing Merinos with other breeds such as the Wiltshire Horn, would rapidly increase breech strike resistance, but will also compromise other desirable production traits such as fine wool in Merinos (Scobie *et al*. 1999, 2002, James 2006).

Considering the negligible loss of wool, the labour savings, the reduced suffering owing to flystrike and the appeal to modern consumers, breech bareness seems a worthy selection goal (Scobie *et al*. 2002).

Bare Breech Phenotype in Merinos

In 2002 a South Australian stud owner observed a Merino ram that developed a bare area around the breech and inner legs at approximately 16 months of age (Hebart *et al*. 2006, Edwards *et al*. 2009). Following the discovery of this ram a number of ewes from the same flock and progeny of the ram have also developed this bare breech phenotype (Hebart *et al*. 2006).

James (2006), in his review article, reported low to moderate heritability estimates for bare area dimensions as quoted for Merinos from an unpublished study by James and Lewer. Hebart *et al*. (2006) reported a moderate to high heritability estimate of 0.46; suggesting a likely increase in the frequency of the bare breech phenotype through breeding.

A new subjective scoring system was devised for Merinos based on the extent of wool coverage on the breech, the inside of the back legs and over the scrotum of rams or udder of ewes to phenotype the trait in ewes and in rams (Edwards *et al*. 2009). Edwards *et al*. (2009) used a scoring system in which the ‘most desirable’ expression of the trait is allocated a score of 1 (1 = bare to 5 = woolly). This scoring system reflects crutch and breech cover, and differs from the scoring system used by many researchers (Tierney 1978, Archer *et al*. 1982, Rathie *et al*. 1994 and Scobie *et al*. 2007) where the highest score was allocated to the highest expression of a trait (i.e. bareness was scored).

High heritability estimates, ranging from 0.45 (Edwards *et al*. 2009 - unmulesed) to 0.48 (Smith *et al*. 2009b - mulesed) were reported for crutch cover score in adult Merino ewes. Crutch cover score at hogget age was also highly heritable, at 0.42 to 0.54 (Edwards *et al*. 2009, Greeff and Karlsson 2009, Smith *et al*. 2009b). Somewhat lower heritability estimates of 0.38 at five months of age (Edwards *et al*. 2009) and of 0.33 at weaning (Scobie *et al*. 2007) were reported for lambs. James (2006) was of the opinion that heritability might increase with age, since estimates at later ages are likely to be more reliable than those at birth because of the difficulty of getting accurate measurements in newborn lambs. The most appropriate age for selection for bareness score is as hoggets when there is no confounding effect of pregnancy or lactation and when the effects of birth type (single or multiple) have diminished (Edwards *et al*. 2009). Greeff and Karlsson (2009) reported a genetic correlation of 0.17 for breech cover score with the incidence of breech strike.

However, Smith *et al*. (2009a) found no evidence that lower breech cover scores were associated with a reduced incidence of breech strike.

The bare breech trait does not appear to have any unfavorable phenotypic or genetic correlations with any of the wool traits measured except weight of the belly wool (Hebart *et al*. 2006, Edwards *et al.* 2009) and weight of skirtings (Edwards *et al*. 2009). Merino sheep with bare breech characteristics can thus be bred (Edwards *et al*. 2009). The timely unearthing of this bare breech phenotype has provided a potential breeding alternative to the practice of mulesing (Hebart *et al.* 2006, James 2006, Edwards *et al*. 2009). Further research also aims to find a genetic marker for the trait to accelerate genetic gain (AWI 2010).

Indicator trait – Dags

Sheep that are less prone to breech strike can be bred, by selecting for reduced wool and wrinkle in the breech area. An alternative approach is to breed for a reduced susceptibility to scouring (Karlsson *et al*. 2001, James 2006). The role of faecal staining in predisposition to breech strike is well established (French *et al*. 1996, 1998). Leathwick and Atkinson (1995) reported a correlation of 0.97 between dagginess and the incidence of flystrike. Diarrhoea or dagginess can be among other factors, caused by helminth infestation and helminth larval challenge. The incidence of flystrike can be significantly reduced by reducing helminth numbers (Morley *et al*. 1976, Watts *et al*. 1978). Breeding for worm resistance *per se* presents challenges in sheep breeding because it is difficult to measure the actual number and biomass of the worms present.

Scientific literature has demonstrated genetic variation in resistance of the host to internal parasites (Gray *et al*. 1992, Gray 1995, Morris *et al*. 1995, 1996, Greeff and Karlsson 1999, Khusro *et al*. 2004). Selection programmes to increase resistance to helminth parasites have been widely promoted in Australia and New Zealand (Baker *et al*. 1991, Woolaston *et al*. 1991, McEwan *et al*. 1995, Pocock *et al*. 1995, Eady *et al*. 1996, Woolaston and Baker 1996, Eady *et al*. 1997, Greeff *et al*. 1999, Morris *et al*. 2000). In South Africa the estimation of genetic parameters for resistance to gastro-intestinal nematodes of sheep is limited to a few studies (Cloete *et al*. 2000, Bisset *et al*. 2001b, Nieuwoudt *et al*. 2002, Cloete *et al*. 2007, Snyman 2007). Faecal worm egg count (FWEC) is generally used as an indicator trait for gastro-intestinal nematode challenge (Greeff *et al*. 1999). Raadsma *et al*. (1997) summarised available heritability estimates for different sheep breeds; ranging from zero to 0.55; with an average of 0.25. The inheritance of faecal worm egg count (FWEC) in Merinos range from 0.15 to 0.42 (Cummins *et al*. 1991, Eady *et al*. 1996, Piper 1987, Albers *et al*. 1987, Woolaston and Piper 1996, Woolaston *et al*. 1991, Greeff and Karlsson 1998, Greeff *et al*. 1999, Pollot and Greeff 2004, Huisman *et al*. 2008). Huisman *et al*. (2008) reported that heritability of faecal worm egg count increases with age.

Although animals may excrete worm eggs at any time of the year, animals do not show their genetic superiority, if they are not continuously challenged by consuming fresh larvae (Greeff *et al*.

1995). No significant associations between worm egg counts and severe dag formation were found in Merino (Larsen *et al*. 1994) or Romney sheep (Baker *et al*. 1991), and it was argued that selection for low worm egg counts is unlikely to reduce the susceptibility of sheep to severe dag formation.

Karlsson *et al*. (1995) found significant differences between the Rylington Merino selection and control line for faecal consistency score (FS), an indicator trait of scouring. Greeff and Karlsson (1998) and Greeff *et al*. (1999) have shown that negative genetic correlations exist between FWEC and FS at weaning and at hogget age. A genetic correlation of 0.93 ± 0.22 was reported between dagscore and FS; suggesting that these traits are genetically very similar (Karlsson and Greeff 1996). Pocock *et al*. (1995) reported a significant negative phenotypic association between dag score and FWEC in a commercial Merino flock. Morris *et al*. (1997) and Bisset *et al*. (1997) reported that lambs selected for a reduced FWEC had more dags than lambs selected for an increased FWEC. Estimates for the genetic correlation between FWEC and faecal staining traits ranged from -0.06 to -0.67 in Merinos as summarised by Larsen *et al*. (1999). Bisset *et al*. (2001a) reviewed other New Zealand studies, which generally show similar relationships. Karlsson *et al*. (1995), Karlsson and Greeff (1996), Greeff and Karlsson (1998) also reported a negative genetic correlation between FWEC and diarrhoea for the Rylington Merino selection line. In a later study however, Greeff *et al*. (1999) reported a low positive correlation on the same selection line, suggesting that an unfavourable relationship may not apply in all situations. In addition, both Greeff and Karlsson (1999) from studies with an unselected hogget flock and Woolaston and Ward (1999) from an analysis of the CSIRO *Haemonchus* selection lines concluded that selection for low FWEC should not result in a significant increase in diarrhoea.

Researchers in New Zealand (Morris *et al*. 1998) and in Australia (Woolaston and Piper 1996, Karlsson *et al*. 1995) have reported that selection for low FWEC resulted in a decreased FWEC. Greeff *et al*. (1999) confirmed that breeding for low FWEC will result in a decreased worm egg output and consequently a reduced contamination of pastures with worms. Appropriate selection strategies can markedly reduce the level of worm burdens (Greeff *et al*. 1999, Morris *et al*. 2000), as well as the infestation of pastures with infective larvae (Greeff *et al*. 2006).

Larsen *et al*. (1995b) have shown that dag score is a repeatable trait in mature ewes and that certain bloodlines are more prone to scouring than others. Direct measurement of either dag score or dag weight can be used as selection criteria for reducing severe dags (Larsen *et al*. 1995b). Leathwick and Atkinson (1995) showed that the percentage of flystruck lambs was correlated with the mean dry weight of dags carried by the treatment group. Scobie (2003) presented evidence that the percentage of lambs struck increases exponentially with increasing dag score.

Bisset *et al*. (1992) and Meyer *et al*. (1983) reported heritability estimates of 0.24 and 0.31 (averaged across several estimates) for dag score, respectively. These values were somewhat lower than corresponding values reported by Watson *et al*. (1986) and Baker *et al*. (1991) of 0.54 and 0.41 respectively. Shaw *et al*. (1999) estimated heritabilities of 0.40 for dag score and 0.16 for faecal consistency in Romney sheep. However, published heritability estimates for dags vary widely with environment and age (Greeff and Karlsson 1998, 1999, Woolaston and Ward 1999). More recently Greeff and Karlsson (2009) reported a heritability estimate of 0.55 for dag score on merino sheep in a Mediterranean environment.

The scientific literature reports a positive phenotypic correlation of 0.23 between dag score and breech strike (Greeff and Karlsson 2009). Dag score is also genetically positively correlated to wool colour score; urine stain score and breech strike with estimates of 0.09; 0.33 and 0.86 respectively (Greeff and Karlsson 2009). Greeff and Karlsson (2009) cautioned that although all the visually scored indicator traits were genetically correlated with breech strike, dags followed by breech cover were the most important indicator trait of breech strike in a Mediterranean environment. They contended that environmental factors will be the key determining factor and that more information is needed to be able to estimate robust genetic and phenotypic parameters for the design of an efficient breeding program.

Murray *et al*. (2007) reported that selecting lambs that had low visual scores for wrinkle, dags and urine stain and high visual scores for bare area was as effective as mulesing sheep to reduce breech strike.

Short tail

A medium to long-term strategy to avoid concern over tail docking would be to cross-breed with short-tailed sheep breeds and/or select for short tails (Scobie *et al*. 1997). Carter (1976) (New Zealand) and James *et al*. (1990, 1991) (Australia) considered using tail length variants to produce genetically docked sheep. Most domesticated breeds of sheep have naturally long tails but there are also many breeds that are short-tailed. Several literature sources also reported on the occurrence of short-tailed animals in otherwise long tailed breeds (Carter 1976, Dennis 1965, 1974, Ercanbrack and Price 1971, Ercanbrack and Knight 1978, James *et al*. 1990). The genetically short tail has a complicated inheritance, because it is associated with more than one gene; however the first-cross progeny have half-length tails (Branford-Oltenacu and Boylan 1974). Branford-Oltenacu and Boylan (1974) was of the opinion that it is a very simple procedure to cross-breed and select for short tails. However, experimental selection of Romneys with short tails, has met with limited success as some of the genes are lethal, causing congenital deformities akin to *spina bifida* (Carter 1976).

Success was achieved in America, with the ‘No-tailed’ sheep breed, but lack of enthusiasm saw their demise in the 1950’s (Jordan 1952 as cited by Scobie *et al*. 1997). Varied effects have been achieved in Merinos (James *et al*. 1990, 1991). More recently the perfect opportunity has arisen in New Zealand with both the Finish Landrace and Gotland Pelt breeds having short tails naturally

(Scobie *et al*. 1997). These breeds arose from the North European short-tailed sheep breeds and could almost be regarded as a subspecies that all have short tails. A genetically short-tailed sheep could readily be retrieved from such breeds (Scobie *et al*. 1997, 1999).

Scobie *et al*. (1997) reported that there would be some loss in fleece weight in the Finn crosses, but that there is evidence for a reduction in fibre diameter which is the primary determinant of price per kilogram (Dobbie *et al*. 1991, Newman and Paterson 1991). Given the rapid responses that have been achieved when selecting for fleece weight (Johnson *et al*. 1995), loose wool bulk (Sumner *et al*. 1995); and staple tenacity (Bray *et al*. 1995); the recovery of wool quantity and quality could be rapid, whilst the change in tail length would be permanent.

However, in New Zealand Pomroy *et al*. (1997) and Scobie *et al*. (1999), in 2 separate studies; using the 0 – 5 scale to score the presence and extent of dags, reported little effect of tail length on dag score although most lambs had few dags.

SCOPE

Against this background, this dissertation investigates managerial and breeding components that could possibly be used in an IPM programme for reduced susceptibility to flystrike under South African conditions. The scope of the problem is such that it is impossible to deal with it exhaustively in a single dissertation. It is also conceded that breech strike is by far the most important form of flystrike in the region. Therefore, much of the content will be naturally inclined to the prevention of this form of flystrike. The study will thus be confined to:

1) A study on the occurrence of flystrike in the region based on survey information in a major sheep producing area.
2) The possibility of using aloe as a natural anthelmintic for the prevention of dags and subsequent breech strike.
3) The estimation of genetic parameters for breech strike and some of the indicator traits reviewed above.
4) The evaluation of responses in breech strike and some indicator traits reviewed above in Merino lines that were divergently selected for their ability to rear multiple offspring. The objective of this part of the study is an attempt to elucidate the feasibility of breeding a robust genotype, with a good reproduction and mothering ability as well as easy-care characteristics and a reduced susceptibility to breech strike.

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PART I

MANAGEMENT OPTIONS

CHAPTER 3

REPORT ON A SURVEY OF THE PREVALENCE OF BLOWFLY STRIKE AND THE CONTROL MEASURES USED IN THE RûENS AREA OF THE WESTERN CAPE PROVINCE OF SOUTH AFRICA

REPORT ON A SURVEY OF THE PREVALENCE OF BLOWFLY STRIKE AND THE CONTROL MEASURES USED IN THE RûENS AREA OF THE WESTERN CAPE PROVINCE OF SOUTH AFRICA

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ABSTRACT

Blowfly strike and the methods used to combat blowfly strike were recorded on 33 properties in the Rûens area of South Africa during 2003/2004. Data were recorded on Merino and Dohne Merino hoggets ($n = 4951$) with at least 3 month's wool growth. The following data were captured: presence or absence of strike, site of the strike (body or breech), presence or absence of dermatophilosis as well as subjective scores for wool quality and wool colour. Control measures that were recorded include: chemical treatment (preventative and spot treatment), crutching, mulesing and the use of the Lucitrap® system. Blowfly strike was not significantly influenced by gender or breed. Hoggets suffering from dermatophilosis were more likely to be struck, compared to contemporaries not suffering from the skin disorder (0.057 versus 0.027; $P < 0.05$). Merino hoggets generally had higher scores than their Dohne Merino contemporaries for wool quality (32.6 versus 27.4; $P < 0.05$) and wool colour (29.0 versus 27.2; $P < 0.05$). There was a suggestion that the presence of the Lucitrap® system may have reduced flystrike, but the effect was not significant, $P = 0.19$ for overall flystrike and $P = 0.12$ for body strike. The Mules operation benefited overall flystrike (0.013 versus 0.110; $P < 0.05$); mainly through an effect on breech strike (0.010 versus 0.109; $P < 0.05$). The proportion of fly strikes increased with wool length, and declined with an increase in farm size and wool colour score. None of the ethically acceptable control measures assessed in the present study could substantially reduce blowfly strike on its own, and an integrated pest management program was proposed.

Keywords: blowfly strike, control methods

INTRODUCTION

The blowfly *Lucilia cuprina* is almost exclusively responsible for primary strikes in South Africa (Howell *et al*. 1978, De Wet *et al.* 1986). Blowfly strike on sheep has been well researched in Australia, New Zealand and in England but research on the sheep blowfly in South Africa is limited to a relatively small number of papers over the last century (Smit and Du Plessis 1927, Smit 1928, Bonsma and De Vries 1943, De Vries1943, De Vries and De Klerk 1944, Fiedler and Du Toit 1956, Blackman and Baker 1975, Howell *et al*. 1978, Viljoen 1978, De Wet *et al*. 1986, Leipoldt 1996, Leipoldt and Van der Linde 1997, Schmid *et al*. 2000, Cloete *et al*. 2001, Scholtz *et al*. 2000, 2001a, b). A survey on blowfly strike in the 1990s suggested that blowfly strike results in an annual estimated loss of R19.8 million to the South African small stock industry (Leipoldt and Van der Linde 1997).

Until recently blowfly control relied largely on insecticides as the first line of defence in most of the major wool producing countries (Howell *et al.* 1978, Hughes and Levot 1987, Leipoldt 1996, Leipoldt and Van der Linde 1997). This generalisation also applies to South Africa. However, certain strains of *Lucilia cuprina* have demonstrated an ability to develop resistance to these chemicals (Hughes and McKenzie 1987, Gleeson *et al.* 1994, Wilson and Heath 1994, Gleeson and Heath 1997, Levot and Barchia 1995, Wilson *et al*. 1996). Fiedler and Du Toit (1956) reported resistance of blowflies against certain organic phosphorous compounds in South Africa as early as the mid 1950s.

Worldwide there is growing concern pertaining to the impact of chemicals on the environment and the potential health risks to humans. This resulted in strict international trade agreements like the Integrated Pollution Prevention and Control (IPPC) Directive (1996) imposed by the European Union (EU). As a result the United Kingdom and EU countries that import raw wool have tightened their regulations concerning chemical residues in wool. The South African Wool Industry as a primarily grease wool exporter cannot afford to ignore this trend, since pesticide residues in wool are likely to have an impact on the future marketing of South African raw wool and the price received for it.

Other control measures against flystrike in use in South Africa include: crutching, tail docking; shearing and until recently the Mules operation (De Wet *et al*. 1986, Leipoldt 1996, Leipoldt and Van der Linde 1997). Changes in social attitudes towards an improved animal welfare have led to the targeting of the Mules operation by animal welfare campaigners (Morris 2000, People for the Ethical Treatment of Animals 2004, Peam 2007). Welfare concerns about the pain and stress associated with the procedure, led to the Australian Wool Industry agreeing in November 2004 that mulesing be phased out by 2010 (Colditz *et al*. 2006, Leary 2006). Internationally there is pressure on all the wool producing countries that make use of mulesing, to stop this practice. The South African National Wool Grower's Association (NWGA) in collaboration with the National Council of Societies for the Prevention of Cruelty to Animals or otherwise known as the South African Animal Welfare Society also responded to this pressure and they announced the following: '*The practice of mulesing is cruel and causes pain and stress to the animal and is a contravention of the Animal Protection Act no. 71 of 1962*' (NWGA 2009).

The other management practices that are currently practiced on the farms in South Africa, when used on their own, are usually not sufficient for complete blowfly control. With limitations to the use of chemicals; restrictions on the Mules operation and limited success with management practices when used on their own, the control of blowfly in South Africa must be revisited. Against this background it was decided to conduct a survey in the Rûens area (Western Cape Province of South Africa) to assess the situation pertaining to blowfly strike and the control methods used to combat it.

MATERIALS AND METHODS

Animals, the environment and recordings

The survey was done during 2003 and 2004 on 33 farms in the Caledon district (situated approximately at latitude 34° 16’ S and longitude 19° 42’ E) and the Riviersonderend district (situated approximately at latitude 34° 08’ S and longitude 21° 11’ E) (Fig. 1). This area is otherwise known as the Rûens area of the Western Cape Province of South Africa and is situated in the foothills of the Swartberg and Langeberg mountains. The topography of the site is sloping, with valleys draining in the south-westerly direction. The climate in this area is Mediterranean with an average annual precipitation of 420 and 429 mm for the Caledon and Riviersonderend areas respectively. Approximately 60% (Riviersonderend) to 70% (Caledon) of the annual rainfall in the Rûens area is recorded between April and September. Small grain cropping, usually associated with sheep farming for meat and wool, are the dominant farming enterprises of the area.

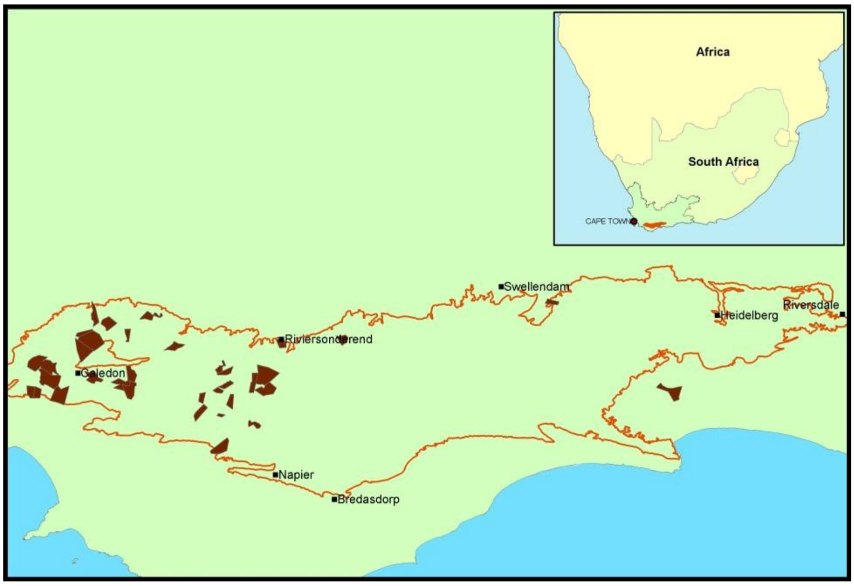

Fig 1. An area chart of the Rûens area depicting the location of the farms where the survey was conducted.

The majority of farms were visited only once, but a number of visits were followed up, resulting in 50 farm visits altogether. During such a visit, young ewe hoggets intended for replacement and in rare cases young wether hoggets (used for wool production) were inspected. On farms with flock sizes exceeding 100 animals, 100 animals were counted off at random and inspected. All the available hoggets were inspected in smaller flocks. During inspection, data were recorded on 4951 Merino and Dohne Merino hoggets with at least 3 month’s wool growth on them. The following data were recorded: presence or absence of strike, site of the strike (body, breech or elsewhere), severity of the strike (1 – mild to 5 – severe: see definition of Scholtz *et al*. 2010a) as well as the presence or absence of dermatophilosis. Strike was recorded if it was observed on the sheep inspected during the visit. Presence of strike was defined as any sign that an observed animal had been struck at any time since the previous shearing, and it was mostly indicated by shorter wool at the position of the strike. Dermatophilosis was subjectively defined as present if, on opening of the fleece, any “Dermo” scabs (as described by Monzu and Mangano1986) were noticed on the skin or in the fleece. The fleece was opened on three places; behind the neck, on the backline and down the side and recorded as present if observed on any of those positions. For the purpose of this study a linear type scoring system was used for wool quality and wool colour (Olivier *et al*. 1987). Quality was defined as sharpness/definition of crimp as well as variation of crimp frequency between fibres and along the staple; from 1 (indistinct evenness of crimp) to 50 (well defined crimp). Wool colour was also scored on a scale from 1 - 50; where 1 equalled yellow wool and 50 equalled white wool. All the animals were subjectively scored for wool quality and wool colour by the same qualified wool classer.

Management strategies and control measures were recorded by interviewing the owner or manager of the farm. Information on crutching, mulesing and the use of the Lucitrap® system was recorded for the mobs under observation. The routine management strategies of shearing and tail-docking were practiced on all the farms, and therefore were not recorded. Other alternative control measures that were used to combat flystrike were recorded and these included: chemical treatment (preventative treatment; spot treatment; chemical and method used) and mulesing. The exact time of chemical treatment and crutching was not recorded.

Animal numbers according to the effects listed above are provided in Table 1, along with unadjusted flystrike frequencies assessed over all animals that were evaluated during the study. Overall strike rates, as well as respective frequencies for breech strike and body strike are presented. Poll strike and pizzle strike were also recorded in one animal each, but these frequencies were too low for meaningful analyses. These cases were, however, included with the overall strike rate. It is notable that wethers as well as animals that were crutched were represented by only small proportions of the overall number of observations.

Statistical analyses

Preliminary Chi-square analyses indicated that frequencies differed ($P < 0.05$) between levels of some of the effects that were considered. However, it was decided to assess all relevant effects in one analysis on each of the dependent variables (overall frequencies of dermatophilosis, flystrike, breech strike and body strike, as well as wool colour and wool quality). Least squares procedures were used for this purpose, to account for uneven subclasses (Table 1). The mixed model that was fitted included the concatenated random effect of farm and year, as well as the fixed effects specified in Table 1. Spot treatment of existing strikes had a 100% incidence and the effect was not considered in any analysis. In analyses on the various measures of blowfly strike the occurrence of dermatophilosis was added as an additional fixed effect. Wool length, wool colour, farm size (ha) and wool quality was added to the model as linear covariates where appropriate.

Initially, random deviations from linearity were also considered. As the inclusion of these deviations did not result in models with a better fit, they were not considered further after initial preliminary analyses. These preliminary analyses included all effects listed, as well as interactions of breed with the absence or presence of the Mules operation, breed with wool length and breed with wool colour. In the case of the three flystrike traits, the interaction of breed with the occurrence of dermatophilosis was also considered initially.

The software used was ASREML (Gilmour *et al*. 2006), which is suitable for the analysis of a wide range of mixed models in agricultural studies on plants and animals. In the case of the binary response variables (the occurrence of flystrike or dermatophilosis), the normal distribution was linked to the binomial distribution by the logit link function (Gilmour *et al*. 2006). The analyses were structured according to type of trait, i.e. of subjective wool traits (i.e. the presence of dermatophilosis, wool colour score, wool quality score), and of blowfly strike traits (i.e. overall flystrike, breech strike and body strike). The approach for the assessment of potential covariates was to model the data using a cubic spline (Verbyla *et al*. 1998). This analysis allowed the assessment of a fixed linear trend, random deviations from linearity conforming to a smooth trend, or random deviations from linearity not conforming to a smooth trend. The latter two terms was not significant and only the fixed linear term was retained in the final analyses. The final runs for the respective trait types only included effects and covariates that approached significance ($P = 0.10$) in preliminary runs for at least one trait in a group. None of the interactions that were considered initially was thus included for flystrike traits. Significant interactions for subjective wool traits were reported in the text. Only those effects, interactions and covariates included in the final runs were tabulated or illustrated graphically and discussed. Logit transformed means are provided with an appropriate standard error of the difference (SED) and the applicable back transformations to proportions on the underlying normal scale. Means for the three flystrike measures and the presence of dermatophilosis was predicted at a wool length of 10 months. Significance at $P = 0.10$ was accepted for flystrike, given the low frequencies of struck animals (Table 1).

RESULTS

General

It was evident that breech strike was by far the most important type of blowfly strike in the present study (Table 1). Slight discrepancies in the observed frequencies can be attributed to 6 animals that had both body strike and breech strike that cancelled out the 2 strikes on other body locations mentioned previously. Furthermore, fairly large absolute differences in flystrike prevalence were observed between ewe and wether hoggets. The prevalence of flystrike in crutched hoggets was also much higher in absolute terms than in their contemporaries that were not crutched. Preventative chemical treatment accordingly did not have the beneficial effect on blowfly strike that was expected. The effects mentioned above did not approach significance at $P < 0.10$ in the overall analyses, and were excluded in final statistical analyses. Recorded cases of body strike were more likely to have strike severity scores of 3 or higher (21/27 = 0.778) than recorded cases of breech strike (80/162 = 0.494) (Chi-square = 6.40; $P < 0.05$).

Table 1. Simple tabulation of effects for animal numbers, as well as the overall frequencies of overall flystrike, breech strike and body strike.

Effect and level	Number of observations	Overall flystrike	Breech strike	Body strike
Year				
2003	3151	0.039	0.033	0.006
2004	1800	0.034	0.032	0.004
Gender				
Ewe	4351	0.034	0.029	0.005
Wether	600	0.063	0.060	0.005
Preventative treatment				
No	1500	0.033	0.028	0.006
Yes	3451	0.039	0.035	0.005
Use of crutching				
No	4644	0.033	0.029	0.004
Yes	307	0.101	0.085	0.019
Use of Lucitraps®				
Yes	1200	0.023	0.023	0.001
No	3751	0.042	0.036	0.007
Use of the Mules operation				
No	3556	0.050	0.045	0.006
Yes	1395	0.004	0.002	0.003
Breed				
Merino	2538	0.033	0.030	0.004
Dohne Merino	2413	0.041	0.035	0.007

Subjective wool traits

Dermatophilosis was more prevalent in wether than in ewe hoggets (Table 2). Merino hoggets generally had higher scores than their Dohne Merino contemporaries for wool quality and wool colour on a subjectively scored scale. Hoggets subjected to the Mules operation generally had higher scores for quality ($P = 0.052$). Results pertaining to dermatophilosis and wool quality were complicated by significant ($P < 0.05$) interactions between breed and the presence of the Mules operation. The presence of dermatophilosis was independent of mulesing treatment in Merinos (Logit transformed means for animals subjected to mulesing or not: -2.09 versus -1.96; SED = 0.41; $P > 0.10$; back transformed means respectively 0.110 versus 0.124). In Dohne Merinos, animals that were subjected to the Mules operation generally had higher levels of dermatophilosis than those that were not mulesed (Logit transformed means for animals subjected to mulesing or not: -1.77 versus -2.69; SED = 0.41; $P < 0.05$; back transformed means: 0.145 versus 0.064). In contrast, quality score was independent of mulesing treatment in Dohne Merinos (means for animals subjected to mulesing or not: 27.6 versus 27.1; SED = 1.1; $P > 0.10$). Merino hoggets subjected to the Mules operation had higher quality scores than those not mulesed (means for animals subjected to mulesing or not: 34.2 versus 31.0; SED = 1.1; *P* < 0.05). There were tendencies for crutched hoggets and wethers to have better quality scores than hoggets that were not crutched (*P* = 0.12) and ewes (*P* = 0.19).

Table 2. Subjective wool characteristics of hoggets evaluated according to breed, gender, the use of crutching, and the use of the Mules operation.

Effect and level	The presence of dermatophilosis		Wool colour	Wool quality
	Logit value	Mean		
Gender				
Ewe	-2.53	0.074^a	28.1	29.6
Wether	-1.73	0.151^b	28.1	30.3
SED*	0.23		0.49	0.6
Breed				
Merino	-2.02	0.117	29.0^b	32.6^b
Dohne Merino	-2.23	0.097	27.2^a	27.4^a
SED*	0.19		0.5	0.5
Use of crutching				
No	-1.60	0.167	28.3	28.5
Yes	-2.65	0.066	27.9	31.5
SED*	0.73		2.5	1.9
Use of mulesing				
No	-1.93	0.126	27.7	29.1
Yes	-2.32	0.089	28.4	30.9
SED*	0.42		1.5	1.1

* Standard error of the difference

^{a,b} Denote significant differences (*P* < 0.05)

The incidence of dermatophilosis (Dermo) was associated with subjective scores for wool quality score and wool colour score (Fig. 2a, b). Predictions on the normal scale suggested that the occurrence of dermatophilosis may be above 60% in sheep with very yellow wool (a wool colour score of 10 or lower; Fig. 2b). This percentage declines to below 5% for sheep with wool colour scores of 40 and higher. In contrast, sheep with higher scores for quality were more likely to suffer from dermatophilosis.

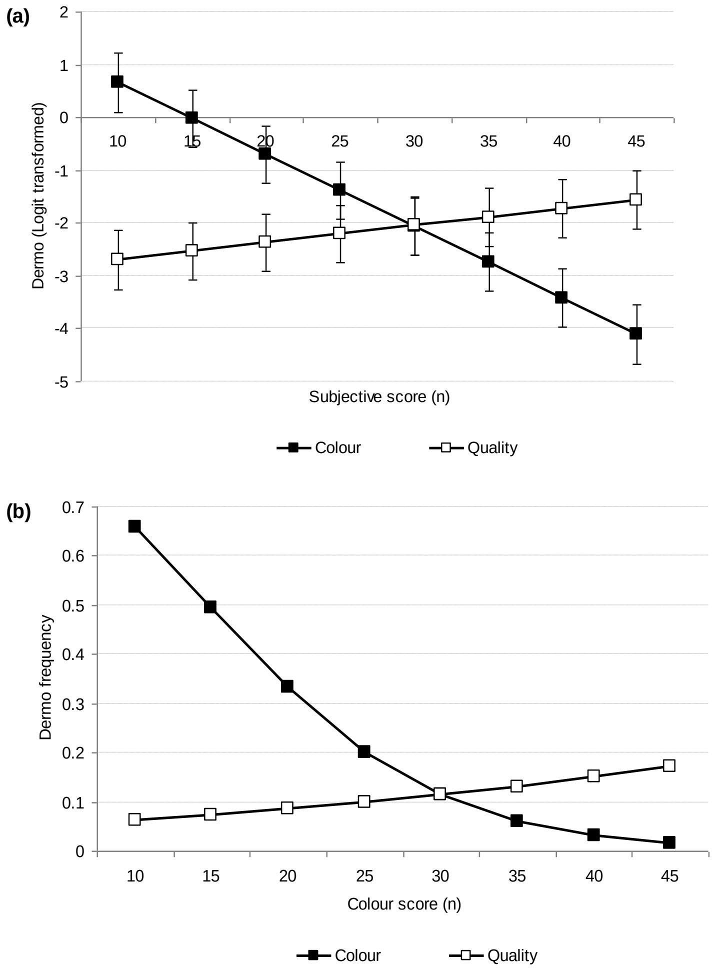

Fig. 2. Predicted means depicting the effects of wool colour and wool quality on the prevalence of dermatophilosis on the logit scale (a), with corresponding back transformed values on the observed normal scale (b). Vertical lines about the mean denote standard errors (a).

Overall flystrike, breech strike and body strike

The prevalence of blowfly strike was independent of breed (Table 3). Absolute values favoured the Dohne Merino breed, and approached significance (*P* = 0.13) for overall strike rate. It is noteworthy that the absolute difference between breeds in Table 3 (0.053 for Merinos versus 0.029 for Dohne Merinos) is reversed in comparison to the uncorrected values in Table 1 (respectively 0.033 versus 0.041). It is important to note that Merino hoggets were much more likely to be subjected to the mules operation than their Dohne Merino contemporaries (1095/2538 = 0.431 versus 300/2413 = 0.124; Chi-square = 574.9; P < 0.01). There was a suggestion that the presence of the Lucitrap® system may result in a reduction in flystrike, *P* = 0.19 for overall flystrike and *P* = 0.12 for body strike. Overall flystrike was reduced (*P* < 0.01) in animals subjected to the Mules operation; mainly through a marked effect on breech strike (*P* < 0.01), while body strike was unaffected by the Mules operation (Table 3). The direction and magnitude of means for animals subjected to the Mules operation and grazing on properties where the Lucitrap® system was employed were fairly consistent between Tables 1 and 3. All forms of flystrike (overall, breech and body) were more prevalent in hoggets suffering from dermatophilosis compared to their contemporaries not suffering from the skin disorder ($P < 0.01$).

Table 3. Overall blowfly strike, breech strike and body strike of hoggets evaluated according to breed, gender, the presence of Lucitrap®, the use of the Mules operation, and the presence of dermatophilosis. Wool length, farm size and wool colour were included as linear covariates. Means were adjusted to a wool growth period of 10 months, and an average wool colour score.

Effect	**Overall blowfly strike**		**Breech strike**		**Body strike**	
	Logit value	**Mean**	**Logit value**	**Mean**	**Logit value**	**Mean**
Breed						
Merino	-2.89	0.053	-3.04	0.046	-5.72	0.004
Dohne Merino	-3.51	0.029	-3.63	0.026	-5.86	0.003
SED*	0.41		0.48		0.57	
Presence of Lucitrap®						
No	-2.80	0.058	-3.05	0.045	-4.91	0.007
Yes	-3.60	0.027	-3.63	0.026	-6.66	0.001
SED*	0.61		0.66		1.1	
Presence of Mules operation						
No	-2.09	0.110^{b}	-2.10	0.109^{b}	-5.39	0.003
Yes	-4.31	0.013^{a}	-4.58	0.010^{a}	-6.19	0.001
SED*	0.70		0.84		0.86	
Presence of dermatophilosis						
No	-3.59	0.027^{a}	-3.69	0.024^{a}	-6.35	0.001^{a}
Yes	-2.81	0.057^{b}	-2.99	0.049^{b}	-5.22	0.005^{b}
SED*	0.19		0.20		0.43	

* Standard error of the difference

^{a,b} Denote significant differences ($P < 0.05$)

The raw proportions of flystrike increased with an increase in wool length (Fig. 3), and declined with an increase in farm size (Fig. 4) and an increase in wool colour score, i.e. whiter wool (Fig. 5).

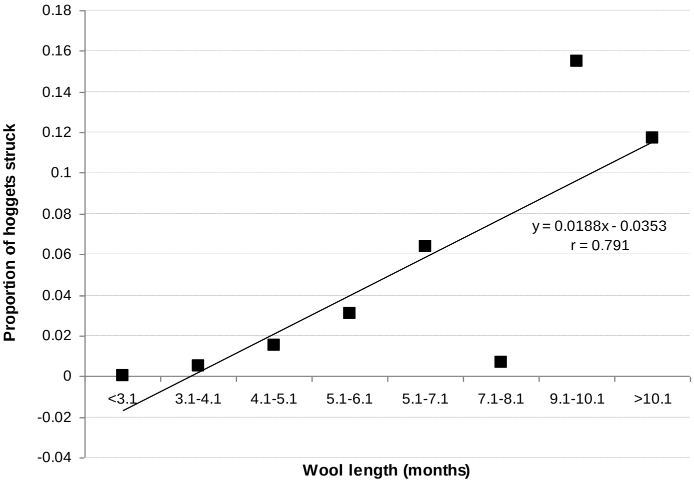

Fig 3. The regression of the proportion of fly strikes on wool length, categorized according to month's growth.

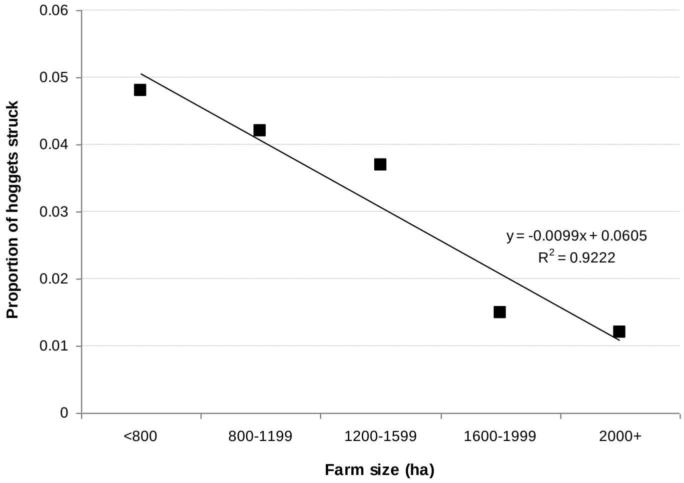

Fig 4. The regression of the proportion of fly strikes on farm size, categorized according to hectare.

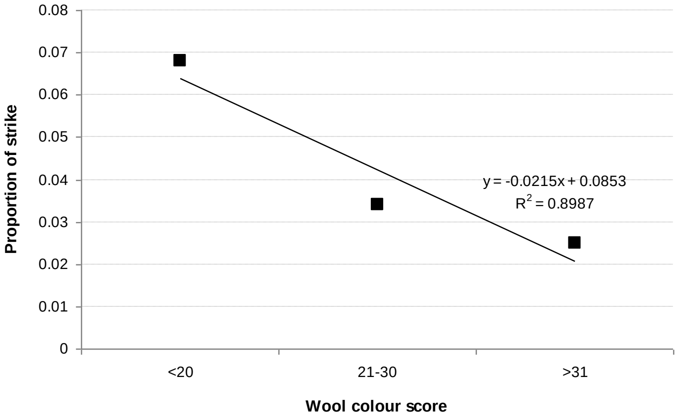

Fig 5. The regression of the proportion of fly strikes on wool colour score. High scores are given for white wool.

When the overall analysis involving all effects was considered, it was clear that the prevalence of overall flystrike and breech strike increased with wool length (i.e. smaller negative values), as was depicted in Fig. 6a. Body strike (which was observed at a reduced prevalence) was not affected to the same extent. Back transformed values in Fig. 6b clearly indicated that the risk of overall flystrike and breech strike were minimal in short-wool sheep, before increasing to 5.5 to 6.0% in hoggets with a wool growth period of 11 months.

In contrast to the observed effect on wool length, the impact of farm size on flystrike was not significant ($P > 0.10$) in the analysis that involved all the other effects. Other effects included in the model may thus have partially contributed to the trend depicted in Fig. 4. Wool colour remained an important source of variation in the prevalence of overall flystrike and breech strike (Fig. 7a, b). Back transformed values suggested that overall flystrike was reduced from ~7% in very yellow wool to below 3% in very white wool.

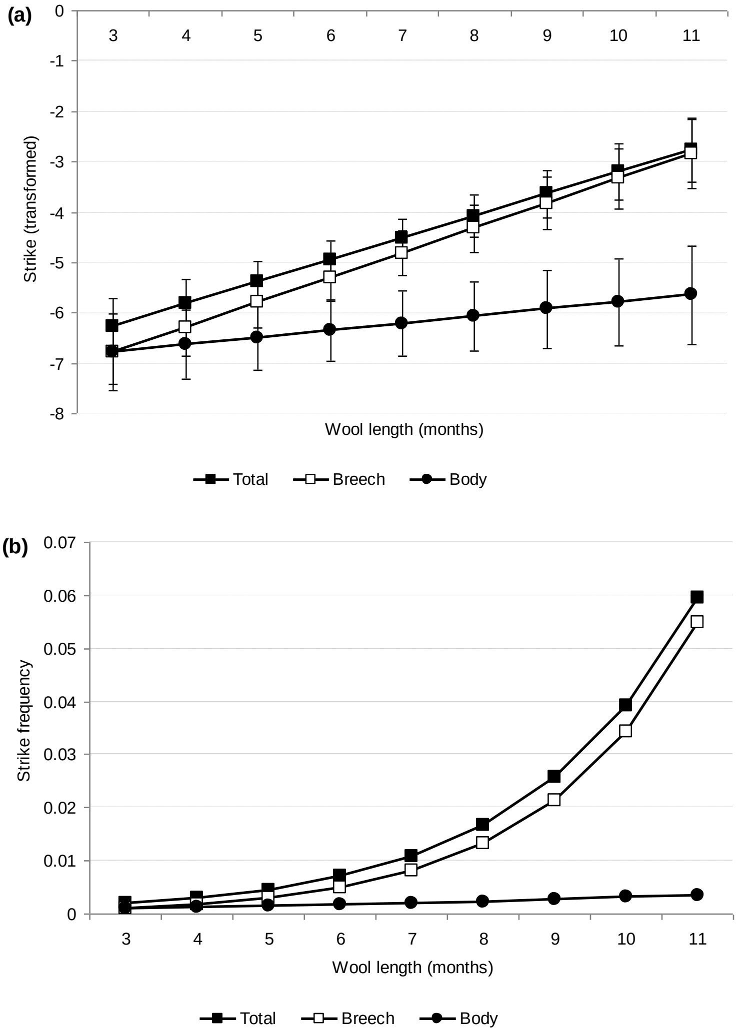

Fig. 6. Predicted means depicting the effect of wool length on the prevalence of total flystrike, breech strike and body strike on the logit scale (a), with corresponding back transformed values on the observed normal scale (b). Vertical lines about the mean denote standard errors (a).

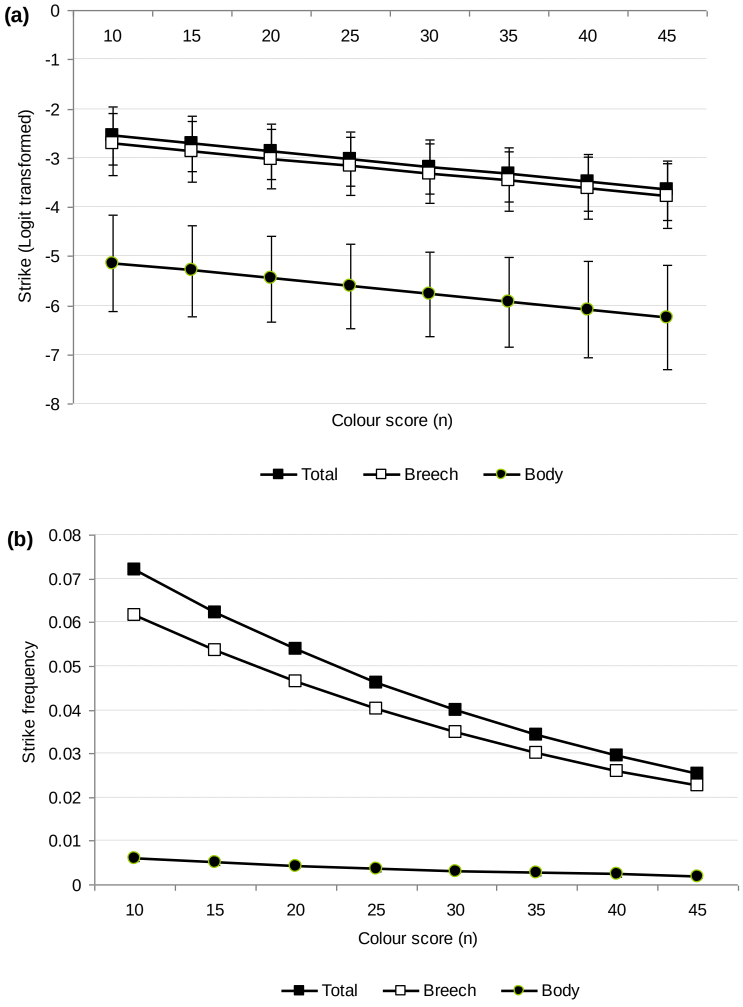

Fig. 7. Predicted means depicting the effect of wool colour on the prevalence of total flystrike, breech strike and body strike on the logit scale (a), with corresponding back transformed values on the observed normal scale (b). Vertical lines about the mean denote standard errors (a).

The effect of wool colour on the frequency of both breech and body strike was appreciably smaller than the effect of wool length. When the standard errors of Fig. 7 were studied there did not appear to be any conclusive differences between the high and lower wool colour scores, although the overall regression coefficient was significant.

DISCUSSION

General

Breech strike appeared to be the dominant form of flystrike in the region under consideration, as was also reported by Cloete *et al*. (2001) for Merino sheep at the Tygerhoek Research Farm (which falls within the region of interest). Similar results were also reported in other parts of the world (Seddon 1931, Belschner 1937a, b, Watts *et al*. 1979, Murray 1980, Murray and Wilkinson 1980, Raadsma and Rogan 1987). The lack of responses in flystrike to preventative chemical treatment was not expected, but may be related to the timing of preventative treatment relative to shearing. The definition of preventative treatment could be problematic, as it could have been in response to strikes that occurred in longer wool sheep. It was also less likely to be implemented in short wool sheep, with a lower susceptibility to flystrike. Data as pertaining to gender and the use of crutching were very unevenly distributed. These effects were not retained in the final analyses, as it was not significant. It is accepted that crutching of sheep has a role to play in blowfly strike control (French *et al*. 1992, Scobie *et al*. 1999), but this was not evident in the present study. It could be argued that crutching may have been in response to flystrike in those 307 animals that were crutched, as their liability to flystrike in absolute terms appeared to be much higher than their contemporaries that were not crutched. In accordance with our previous observations (Scholtz *et al*. 2010a), body strike appeared to be more severe than breech strike. It was suggested that the former type of flystrike could be more difficult to detect during routine inspections than the latter, a contention which is supported by the present results. It is conceded that date of shearing could have influenced flystrike but this effect was confounded by wool length in the present study, and therefore not assessed.

It is conceivable that fixed effects based on the treatment of entire mops at properties (crutching, preventative treatment, mulesing, etc) could have been based on knowledge on flystrike risk on those properties. This could potentially influence results of this study, as such considerations were not known to the surveyor. If this reasoning is founded, it would support the effectiveness of mulesing in the alleviation of breech strike, and it would also strengthen the tendency towards lower levels of flystrike on those properties where the Lucitrap® system is employed.

The ideal would be to classify properties prior to the survey according to their flystrike risk; however, since no historic information on the respective properties was available this was not possible. It is, however, conceivable that properties with high flystrike risk could rely on preventative practices such as crutching, mulesing and trapping.

Given the relative homogeneity of the experimental area in terms of climate, topography and farming practices this does not seem likely. Of course, the effects measured on individual sheep do not suffer from this complication.

Subjective wool traits

Dermatophilosis appeared to be more prevalent in wether than in ewe hoggets in our study (Table 1). In contrast, Edwards *et al*. (1985) reported an average prevalence of respectively 0.2% versus 0.6% for wether and ewe lambs, in a survey on ovine dermatophilosis in Western Australia. They further stated that the prevalence of dermatophilosis and its relationship to various environmental and management factors varied with the age and gender of sheep in their study. Wethers are valued for their meat, since meat typically contributes largely to the income of wool farmers in South Africa (Olivier 1999). The result from this survey can probably also be attributed to management factors, with ewe flocks generally well looked after while little effort and money is spend on wether lambs before they are sold for slaughter. However, this is pure speculation since management practices for the control of dermatophilosis were not recorded. It also needs to be stated that the number of wethers in the survey was small compared to the ewes, and coincidence may have played a role.

Merino hoggets generally had higher scores for wool quality and wool colour than the Dohne Merino hoggets when scored subjectively (Table 1). The Merino is valued for its fine quality wool (Bosman 1933, Jones *et al*. 1946). The Dohne Merino, developed from the Merino and South African Mutton Merino (formerly the German Merino), was originally intended for semi-intensive farming in the Eastern Cape grassland regions (Kotzé 1951). It has proved itself adaptable under widely divergent conditions and is considered one of the main dual-purpose breeds of South Africa. In a comparative study between Merino and Dohne Merino yearlings, average fibre diameters of 21.8 µm versus 22.0 µm for rams and 21.9 µm versus 21.8 µm for ewes were recorded for the respective breeds (Cloete *et al*. 1999). In a more recent study by Herselman (2006) fibre diameter was reported to be 18.0 µm for Merinos and 19.7 µm for Dohne Merinos. Even though Dohne Merino wool can be considered to be of the same fibre diameter as medium to fine Merino wool when measured objectively, a significant difference ($P < 0.05$) of 32.6 (Merinos) versus 27.4 (Dohne Merinos) in terms of quality (evenness and boldness of crimp, softness of handle and the absence of strong and hairy fibres) of the wool was observed. Where wool colour is concerned, a significant difference of 27.2 (Dohne Merino) versus 29.0 (Merino) ($P < 0.05$) was reported. Unfortunately the authors could not find any comparative study in terms of wool colour or wool quality between the Merinos and Dohne Merino breeds to support or refute the present findings. It needs to be stated that wool from German Merinos (one parent breed of the Dohne Merino) was considered to have a yellowish appearance initially. It is noteworthy to mention that Belschner (1953) was of the following opinion '*I regard yellow colouration of the yolk as an important factor in rendering sheep susceptible to fleece rot, but I regard character and "handle" (softness of the wool) as more important factors than colour'*

The interactions between breed and mulesing status for the presence of dermatophilosis, as well as for quality, warrant some discussion. In the case of dermatophilosis, this interaction could be considered to be spurious, as the interaction seems to be driven mostly by a low incidence of dermatophilosis in the numerically small group of Dohne Merinos that were subjected to the Mules operation. However, in the case of quality, the interaction seemed to be caused by better scores in mulesed Merino hoggets, which were numerically very similar to those Merino hoggets not subjected to mulesing. As the Mules operation was at that time considered as a routine managerial intervention on well-managed farms, it may be argued that those Merino farmers that practiced mulesing may actually have been more committed sheep farmers, hence the better wool quality in their stock.

Overall flystrike, breech strike and body strike

Blowfly strike was independent of breed (Table 3), although absolute values favoured the Dohne Merino and approached significance for overall flystrike (*P* = 0.13). The discrepancy between raw means for overall flystrike in Table 1 and adjusted means in Table 3 stems from the adjustment of flystrike data of Merinos for the difference in wool colour, as well as for a much higher prevalence of the Mules operation in the latter breed. This survey was done on young animals and young animals are known to be very susceptible to blowfly strike. Raadsma (1991) reported young sheep, regardless of gender, with 3 – 6 month's fleece growth to be the most susceptible to body strike. With an overall raw blowfly strike rate of below 4%, and with a body strike prevalence of below 0.5%, the challenge might have been too low to express any difference in blowfly strike susceptibility that may exist between these breeds. The blowfly strike rate reported in this study is in accordance with strike rates ranging from 1.6% to 15% reported elsewhere (Wardhaugh and Morton 1990, French *et al*. 1992, Heath and Bishop 1995, Leipoldt and Van der Linde 1997).

As pertaining to the Lucitrap® system, absolute values for flystrike favoured properties where trapping was employed as a component of integrated pest management (Tables 1 and 3). In the case of body strike, this difference approached significance (*P* = 0.12), although it needs to be conceded that body strike occurred at a very low prevalence. The effectiveness of the Lucitrap® system in reducing blowfly populations was demonstrated in Australia (Urech *et al*. 1996, 1998) and in South Africa (Scholtz *et al*. 2000, 2001a, b). Ward and Farrell (2001) reported a 46% reduction in strike rate in a trial conducted in southern Queensland by using the Lucitrap® system. According to Table 3, the absolute value for overall flystrike in trapped areas (2.7%) amounted to 46.6% of that in areas where no traps were placed (5.8%). Clearly, this result is in close correspondence with the report from Ward and Farrell (2001). However, an important factor to consider in monitoring fly populations is how the numbers of the flies caught relate to incidence in flystrike in sheep flocks (Cottam *et al.* 1998). In a study by Wardhaugh and Morton (1990) it was reported that the incidence of flystrike was related to the logarithm of the density of gravid females in the area during the previous week. As a result of the logarithmic relationship, a reduction of fly numbers by 70% would be necessary to reduce flystrike by 50%. Scientific literature reported that intensive use of the Lucitrap® system and a high level of fly-trapping for several years may reduce the blowfly problem to more manageable levels (Ward and Farrell 2001) but are unlikely to prevent all flystrike overall (Heath 1994, Evans and Karlsson 2009). Furthermore the large numbers of adult females that need to be attracted by traps to achieve effective population management (Broughan and Wall 2006) thereby allowing a mentionable reduction of pesticide treatment (Wardhaugh and Morton 1990, Horton *et al*. 2001) is seldom achievable. It is interesting to note that Smit (1928) was already of the opinion '*that the trapping of blowflies must be a supplementary measure, since even though substantial numbers of flies may be caught in traps the numbers caught in a trap does not always indicate the amount of good the trap is doing'.* Scientific literature recommends the use of fly traps in combination with other management systems to keep flystrike at low levels (Evans and Karlsson 2009).

The Mules operation benefited overall flystrike (1.3% versus 11.0%; for mulesed and unmulesed hoggets respectively; $P < 0.05$). The Mules operation is known to be highly effective at reducing the incidence of strike in the breech (Luff 1976, Watts *et al*. 1979, Morley and Johnstone 1984, Marchant 2003, Lee and Fisher 2007, Rothwell *et al*. 2007). This also held true for this study where the incidence of breech strike was reduced more than tenfold from ~11% in unmulesed hoggets to ~1% in mulesed hoggets. Mulesing is permanent and can reduce the prevalence of breech strike from 60 - 80% in ewes to less than 1% when combined with crutching (Raadsma 1991). However, in terms of animal welfare, it can not be considered a control option for breech strike anymore. With the restriction on the use thereof in South Africa alternative measures need to be considered for the control of breech strike. Body strike was independent of mulesing, as would have been expected. The liability of hoggets suffering from dermatophilosis to flystrike was about double that of contemporaries not suffering from the skin disorder (Table 3). In the present study, this difference was evident both for breech strike and for body strike. The latter finding is in accordance with scientific literature reporting dermatophilosis to be one of the main predisposing conditions for body strike in particular (Monzu and Mangano 1986, Gherardi *et al.* 1981, Sutherland *et al*. 1983, Horton 1999). Furthermore, immunologically ‘naïve’ sheep such as the locally-bred young sheep in this survey are expected to have a higher susceptibility during their first challenge period (Karlsson *et al*. 1999).

The proportion of fly strikes increased with wool length (Fig. 1 and Fig. 3) as was expected. Already in the early history of the wool industry, MacLeod (1943) identified wool length as the factor dominating the susceptibility of sheep to blowfly strike. It is furthermore accepted that clipped sheep and young lambs with short fleeces (2 - 3 month’s wool growth) are not usually struck, but as the length of the fleece increases so does the risk of strike (French *et al*. 1996).

The decline in proportion of strikes with an increase in farm size in Fig. 2 was not supported in the analysis that involved all effects with an influence on flystrike. It therefore seems that other effects, accounted for during the rigorous statistical analysis, were associated with this trend, rather than farm size *per se*.

There was a decline in proportion of strikes as wool colour became whiter (Fig. 3 and Fig. 5). The result from this study is in accordance with scientific literature reporting that sheep with bright, white wool are generally more resistant to fleece rot and body strike than those with yellow wool (Wilkinson 1986, Evans and Karlsson (2009). Various researchers (Belschner 1937b, Hayman 1953, Paynter 1961, McGuirk and Atkins 1980, James *et al*. 1984, 1987) have looked for indirect selection criteria to identify sheep that are more resistant to fleece rot and therefore more resistant to flystrike. Greasy wool colour (yellowness) has been reported to be the character most strongly associated with fleece rot in South Australian Merinos (James *et al*. 1984, 1987), while it is also consistently related to fleece rot in studies with other Merino strains (Belschner 1937b, Hayman 1953, Paynter 1961, McGuirk and Atkins 1980, Farquharson 1999, Karlsson *et al*. 2008).

Moderate to high heritability estimates (0.3 – 0.64) have also been reported for greasy colour score in Australia (Morley 1955, McGuirk and Atkins 1980, James *et al*. 1987). Wool colour score of South African Merino sheep was accordingly reported to be highly heritable at 0.33 (Matebesi *et al*. 2009). Therefore selective breeding for sheep with bright white wool may reduce the incidence of flystrike (Mortimer 2001a, b).

The aim of the wool sheep industry is sustainable ectoparasite control (Karlsson 1997). The most efficient method to achieve this aim is through Integrated Pest Management (IPM) programs. International trade agreements favour an IPM approach for the control of the control of insect pathogens, including the sheep blowfly.

CONCLUSIONS

This study concludes that breech strike is the major form of strike in this area. Ironically, mulesing was once again demonstrated to be an effective control method for breech strike. With the termination of mulesing as an acceptable management practice, the study highlights the need for alternative methods to be used in blowfly IPM. It is notable that other initiatives that could add to blowfly IPM and recorded in the present study failed to have the same impact on blowfly strike than mulesing had. Indicator traits associated with blowfly strike included the presence of dermatophilosis and wool colour score in the present study. Recent research in Australia identified more such indicator traits with potential to combat breech strike, namely: wrinkle-; dag-; urine stain-; breech cover and crutch cover scores as well as wool characteristics as indirect selection criteria for the control of breech strike. This opens up the opportunity of a genetic solution to the breech strike problem in the Rûens area. Although breeding is a long-term solution, it is attractive from animal welfare, ethical, economic and sustainability perspectives. Based on recent results, it seems feasible for selective breeding to contribute to blowfly IPM (Greeff and Karlsson 2009, Scholtz *et al*. 2010b), and the topic clearly warrants further research.

Since none of the management practices in use on the farms surveyed were sufficient to guarantee complete blowfly control when evaluated on their own, an IPM approach should be considered. An IPM approach for the control of blowfly strike should include sheep husbandry, farm management; selective breeding and strategic insecticide usage.

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CHAPTER 4

THE ASSESSMENT OF CRYSTALS DERIVED FROM *ALOE* SPP. FOR POTENTIAL USE AS AN ANTHELMINTIC THEREBY INDIRECTLY CONTROLLING BLOWFLY STRIKE

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THE ASSESSMENT OF CRYSTALS DERIVED FROM *ALOE* SPP. FOR POTENTIAL USE AS AN HERBAL ANTHELMINTIC THEREBY INDIRECTLY CONTROLLING BLOWFLY STRIKE

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ABSTRACT

Dagginess predisposes sheep to breech strike. On the assumption that dagginess can be controlled by managerial and husbandry interventions, breech strike can arguably be controlled with such practices or by simply treating the animal with an anthelmintic. The effect of regular treatment with crystals derived from *Aloe* spp as a natural anthelmintic over an extended period (four to eight months) was assessed in yearling Merino progeny born in 2004 (Trial 1) and 2005 (Trial 2). The short-term effect of aloe treatment was also considered in a separate trail (Trial 3). Animals were randomly allocated to each treatment group (i.e. aloe or distilled water). Natural challenge was used to ensure that all animals received an adequate gastro-intestinal nematode challenge, prior to being drenched with an aloe solution, or with distilled water as a control treatment. The variance components for animals were used to derive repeatability coefficients for FWEC. When monthly FWEC was considered in Trial 1 and 2, there was no evidence of a reduced parasite burden in the treated group. Similarly, no change was found in Trial 3, where the short-term effect of treatment was considered. No significant selection line differences were found for FWEC. The mean dag scores of individuals in Trial 1 and Trial 2 were accordingly not affected by treatment with aloe. Alternative strategies for the reduction of FWEC and flystrike thus need to be considered.

Keywords: aloe, anthelmintic, FWEC, Merino, breech strike

INTRODUCTION

An indirect method to control blowfly is to reduce dagginess by sheep thereby making them less attractive for breech strike. Dags are accumulations of sometimes large masses of faecal material around the tail and crutch of sheep and are typical of sheep with loose, moist faeces adhering to the wool (Reid and Cottle 1999, Waghorn *et al*. 1999). Dags represent a major cost to sheep farmers, in monetary terms (Larsen *et al*. 1995) and because of the stress to the sheep associated with flystrike (Waghorn *et al*. 1999). Gastro-intestinal nematode parasite infections have been associated with dag formation (Watts *et al*. 1978, Larsen *et al*. 1994, McEwan *et al*. 1992). The control of helminth infections in livestock relies mainly on the use of anthelmintics (Leiper 1951, Morley *et al*. 1976, Watts and Marchant 1977, Watts and Luff 1978, Morley 1983, Piper and Barger 1988, Waller 1994) in combination with managerial practices. “Modern, chemical" anthelmintics however, are under scrutiny because of increased parasite resistance due to long-term and continuous application (West *et al*. 1989, Van Wyk *et al*. 1997a, Waller 1998, Bisset *et al*. 2001, Satrija *et al*. 2001) and are perceived as unnatural and sometimes harmful to the environment. International trade agreements also strive for less reliance on chemicals and there is a move towards more natural or “organic” farming.

Livestock are reared under a wide variety of production systems ranging from large-scale intensive commercial farms to traditional smallholder and village production systems (Satrija *et al.* 2001, Uncini Manganelli *et al*. 2001). The livestock component is an important and integrated component of agricultural production systems in developing countries. Unfortunately livestock farmers in many developing countries cannot use commercial anthelmintics in intestinal parasite control programmes for a number of reasons, including the unavailability or erratic supply of the drugs, the costs involved and the size of packaging (packed for flock sizes of 50 - 100 head, which is more than the average number per family in resource poor communities) (Satrija *et al*. 2001). Farmers in developing countries have used traditional medicinal plants to control internal parasites for centuries. It is thus possible that medicinal plants may become viable alternatives for modern synthetic anthelmintics in resource poor agriculture if their efficacy can be proofed scientifically in controlled studies (Satrija *et al.* 2001). It has to be recognized that there is a long tradition of ethno-veterinary remedies and practices for the most common animal diseases including internal or external parasite infections (Uncini Manganelli *et al*. 2001). Mathius-Mundy and McCorkle (1989) defined ethno-veterinary medicine as dealing with 'the folk beliefs, knowledge, skills, methods and practices pertaining to the health care of animals'. Fielding (2009) defined ethno-veterinary medicine as the medicines that livestock keepers are using, other than modern synthetic drugs.

Aloe ferox is used to a great extent in traditional human and livestock medicines (Van Wyk *et al*. 1997b), for example, poultry are protected from tick and lice infestations when fresh Aloe leaves are put into their drinking water (Dold and Cocks 2001). This may suggest that Aloe has a repellent effect on some insects. *Aloe* spp. are members of the Liliaceae family and are mainly succulents. The nearly 420 species of Aloe are confined mainly to Africa. *Aloe ferox* is among the tallest of the local species, and is native to the south-eastern and western regions of South Africa. Compared to the widely known *Aloe vera*, *Aloe ferox* produces 20 times more bitter sap and has higher nutrient concentrations (Anonymous 2004). *Aloe ferox* is not considered an endangered species (Anonymous 2004) and is not listed on the United States Endangered Species Act list, i.e. the internationally maintained Red List of Threatened Species or the CITES list of endangered species.

Fig. 1. An Aloe plant – a member of the Liliaceae family.

Aloes (Fig. 1) are robust plants with persistent dry leaves on the lower portion of the single stem. The broad, fleshy leaves are dull green or reddish-green, with dark brown spines along the edges and sometimes on the lower surface (Van Wyk *et al*. 1997b). All broad leaf Aloe species have basically the same leaf structure. A tough green outer layer encloses the translucent fleshy portion of the leaf (Anonymous 2004). There are two distinct parts of the plant that are harvested, namely:

- the yellow exudates (known as the bitter sap) that drains from the outer skin of the leaves when cut, and
- the remainder of the leaf that contains the mucilaginous gel (Anonymous 2004).

The bitter yellow juice, which exudes from just below the surface of the leaf, is dried using an age-old method to produce a dark brown resinous solid, known commercially as aloe lump or Cape aloes (Van Wyk *et al*. 1997b).

Some commercial farmers in South Africa are becoming more interested in 'organic' farming. An organic farmer promoted the use of Aloe to control parasites in sheep and alleged that the use of Aloe resulted in a reduction in FWEC. Most of the farmers that make use of an Aloe treatment put the crystals in a little material bag in the troughs of the animals. The crystals then dissolve slowly in the drinking water of the animals. The organic farmer, however, dosed his animals with an Aloe solution. Since the study was not conducted according to a proper scientific method, it needs verification. If Aloe is shown to be an effective replacement for synthetic anthelmintics it would also benefit the commercial sector and organic farmers in particular. Furthermore, it is worthwhile testing if Aloe has a direct repellent effect on blowflies, adding to possible benefits ascribed to a reduced dagginess. Two hypotheses were tested, namely:

- the administration of aloe as a natural anthelmintic will have a beneficial effect on faecal worm egg counts of Merino yearlings under conditions of natural challenge
- the administration of aloe will reduce dag score of Merino yearlings under natural challenge conditions, thus rendering them less susceptible to breech blowfly strike.

MATERIALS AND METHODS

Animals, selection procedures and location

The resource flock used were Merino sheep that were divergently selected for reproduction as described by Cloete *et al*. (2004). Initially two lines of Merino sheep were divergently selected from the same base population since 1986, using maternal ranking values (Turner 1977) for lambs reared per joining. Ewe and ram progeny of ewes rearing more than one lamb per joining (i.e. reared twins, at least once) were preferred as replacements in the High (H) line. For the Low (L) line, replacements were preferably descended from ewes rearing less than one lamb per joining (i.e. barren or lost all lambs born, at least once). More details with regard to the selection procedure for replacements for the two lines can be found in the literature (Cloete and Durand 1994, Cloete and Scholtz 1998, Cloete *et al*. 1998, Cloete *et al*. 2004). During 2003 two additional crossbred lines were formed when part of the breeding flock was subjected to reciprocal crossbreeding between the two lines, with the intention of forming a genetic resource population for possible future genomic projects (Naidoo *et al*. 2005). Crossbred progeny was thus available from the 2003 year of birth onwards. Animals from these crossbred lines were backcrossed onto the H line and the L line, backcrosses becoming available from 2005. For the purpose of this study progeny from four selection lines (H line, L line, H x L line and L x H line) were available in the 2004 (Trial 1) study. Progeny from six selection lines (H line, L line, H x L line, L x H line; backcross to H line and backcross to L line) were present in the 2005 (Trial 2) study. Since their establishment these lines were maintained as a single flock, except during joining.

For the duration of the study, the lines were maintained on the Elsenburg Research Farm (33° 51' S, 18° 50' E) near Stellenbosch, in the south-western region of South Africa. The climate at the experimental site is Mediterranean, with 78% of the average rainfall of 606mm being recorded in the months from April to September.

The study comprised of three separate experiments. The effect of long-term treatment with Aloe was assessed in yearling progeny of the resource flock born during 2004 (Trial 1) and 2005 (Trial 2). The available progeny were stratified according to live weight and animals were randomly allocated within weight classes and selection lines to the treatment or the control group.

Natural challenge was used to ensure that all animals received an adequate gastro-intestinal nematode challenge, prior to being drenched with Aloe, or distilled water as a control treatment.

The day (between 14h00 – 16h00) prior to dosing the animals, 75g of a commercially available Aloe powder was dissolved in 1 litre of lukewarm distilled water. The solution was stirred, left overnight and stirred again. The supernatant was decanted for use and the resin-like deposit discarded. The method for preparing the solution as well as dosage used was suggested by the organic farmer that dosed his animals with Aloe. This procedure was repeated 8 times in 2004 and 4 times in 2005, at approximately monthly intervals.

Gastro-intestinal nematode egg counts were obtained at regular intervals to assess the effect of the aloe treatment. All experimental animals were dosed with either 10cc of distilled water or with 10cc of the abovementioned Aloe solution after the faecal samples were taken. Dosing was done by administering the treatment with a dosing gun. In the 2004 progeny group, samples for assessing FWEC were acquired during October 2004, December 2004, January 2005, February 2005, March 2005, April 2005, May 2005 and July 2005. The experiment was replicated with progeny born during 2005. Sampling dates for the progeny born during 2005 were January 2006, February 2006, March 2006 and June 2006. In the third (short term) study, FWEC was determined immediately prior to drenching (day 0) and on day 3 and day 14 (Trial 3). Decisions for dosing of control (and/or treatment) animals with conventional anthelmintics for welfare purposes were based on these counts. The identity of each animal and the type of treatment it received were recorded where necessary. All progeny were shorn as weaners in October and had short wool during the peak blowfly season. Very few blowfly strikes were therefore recorded, and these data were not analysed. Dag scores for individual animals were recorded prior to shearing, using a visual scoring procedure with scores from 1 to 5 (Fig. 2).

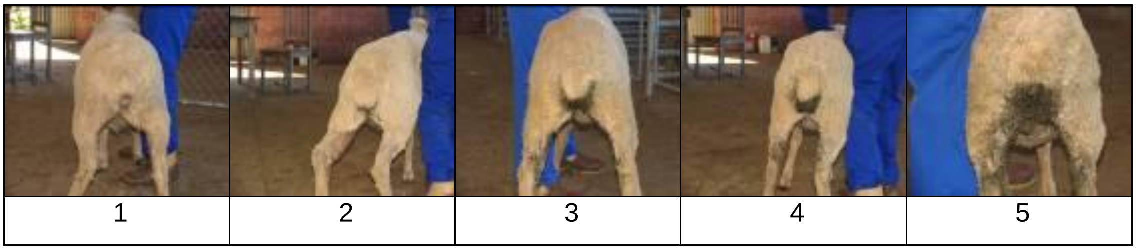

Fig. 2. Scoring method to score dags in sheep.

Statistical methods

The same basic statistical methods were followed for the three experiments. The experimental outlay was factorial, with aloe treatment and sampling date as main effects. As outlined above, eight sampling dates were considered in Trial 1, four in Trial 2, and three in Trial 3. As the same animals were sampled repeatedly in all experiments, the random effect of animal was included in all statistical analyses involving FWEC. ASREML software (Gilmour *et al*. 1999) was used for this purpose.

The software allows the fitting of various random effects in animal breeding, while also making provision for the prediction of least-squares means for fixed effects of interest. Apart from treatment and sampling date, the effects of selection line (H line, L line, H x L line and L x H line for Trial 1; H line, L line, H x L line, L x H line, backcross to H line and backcross to L line for Trial 2) gender (male and female) and birth type (single and pooled multiples) were also considered as fixed effects. No additional fixed effects were considered in Trial 3, where a relatively small number of animals were involved. Two-factor interactions between the relevant effects were also considered, but were only retained in the final analysis when pertinent to the outcome of the study (treatment x sampling date) or significant ($P < 0.05$). Recordings of FWEC were subjected to the cube root transformation prior to analyses to normalise the distribution in all cases. The variance components for animal were used to derive repeatability coefficients for FWEC, as described by Turner and Young (1969). The same basic procedure was used for the analysis of dag scores. However, since only one record was available per animal, the effects of animal and sampling date were dropped from the analyses.

RESULTS AND DISCUSSION

Derived untransformed means (± s.d.) for FWEC indicated extreme variation between and within trials, being 1030 ± 1705 epg faeces for Trial 1, 3284 ± 3713 epg faeces for Trial 2 and 853 ± 477 epg faeces for Trial 3. The cube root transformation was effective for normalising the variation and respective raw means of 7.88 ± 4.65, 13.2 ± 4.97 and 8.59 ± 3.12 epg faeces were computed for the respective experiments (Table 1). Derived repeatability coefficients were low, namely, 0.040 ± 0.030 for Trial 1, 0.123 ± 0.056 for Trial 2 and 0.054 ± 0.121 for Trial 3.

Table 1. Overall least squares means (± s.e.) for cube root transformed FWEC in animals treated with aloe or distilled water (Control) during Trials 1 to 3.

Trial	Treatment		Significance
	Aloe	Control	
Trial 1 (2004) progeny	8.3 ± 0.3	8.1 ± 0.3	n.s.
Trial 2 (2005) progeny	13.9 ± 0.5	14.3 ± 0.6	n.s.
Trial 3 (short term)	8.8 ± 0.5	8.5 ± 0.5	n.s.

n.s. – not significant (*P* > 0.10)

The administration of aloe did not affect the overall cube root transformed FWEC in any of the Trials (Table 1). When monthly FWEC in the long term studies (Trials 1 and 2) were considered as an interaction between aloe treatment and month, there was no evidence of a reduced parasite burden in the treated group (Fig. 3a and 3b). Similarly, no change was found in Trial 3, where the possible shorter term effects of treatment were considered (Fig. 3c).

Fig. 3a

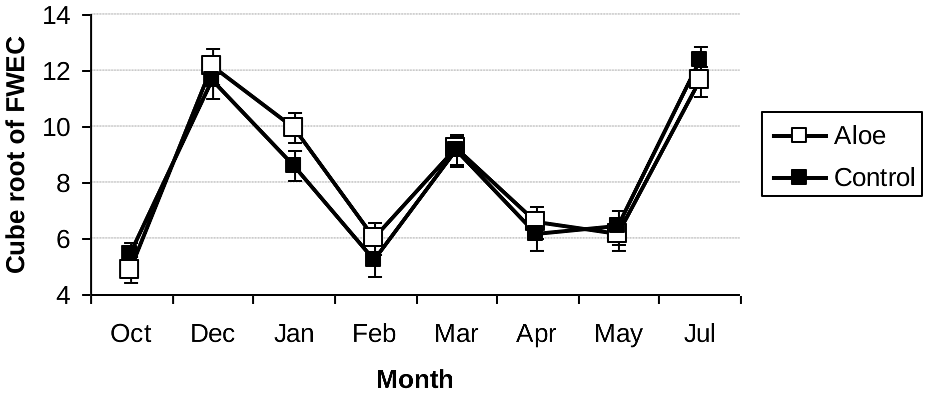

Fig. 3b

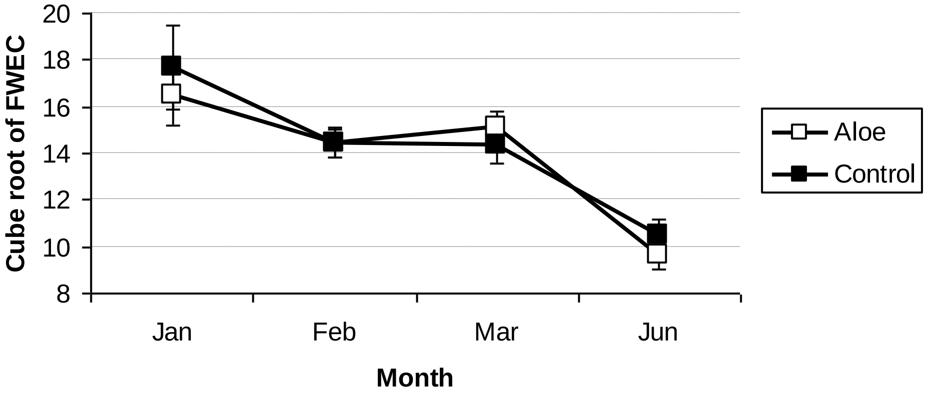

Fig 3c

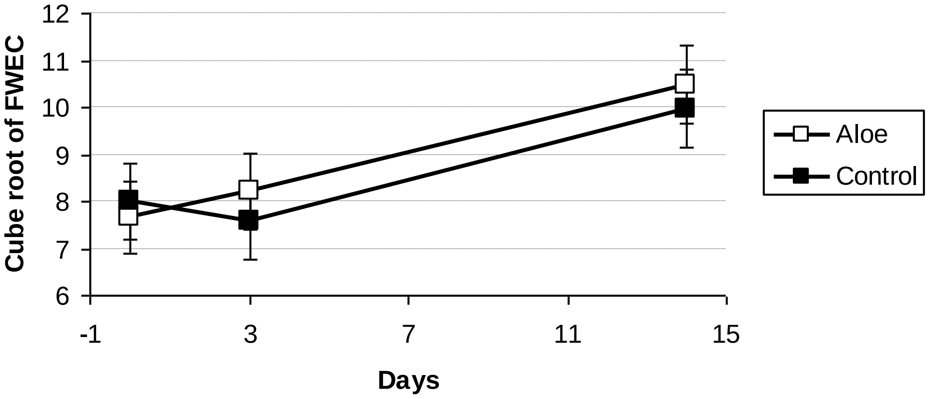

Fig. 3. The interaction of treatment with aloe or distilled water (Control) with sampling date for Trial 1 (Fig 3a), Trial 2 (Fig 3b) and Trial 3 (Fig 3c). Vertical lines about the means represent standard errors.

It is possible that the dosage used might not have been appropriate for the gastrointestinal challenge in the animals studied. Animals in the Karoo area (semi-arid area where the organic farmer lives) tend to have lower gastrointestinal challenges than those maintained in the Western Cape; therefore the dosage might have been adequate for animals in the Karoo but not in the Western Cape. It is furthermore possible that a different method of administration may have given different results, since the putative active substance in the Aloe solution might have been subjected to microbial degradation in the rumen and therefore not as effective.

No significant selection line differences were found for FWEC (Table 2). Selection line was accordingly not involved in interactions with treatment or sampling date ($P > 0.10$).

Table 2. Overall least squares means (± s.e.) for cube root transformed FWEC in animals belonging to the respective selection lines in Trials 1 and Trial 2.

Selection line	Trial 1	Trial 2
H line	7.94 ± 0.22	13.5 ± 0.4
L line	8.69 ± 0.53	14.7 ± 1.0
H x L line	8.16 ± 0.36	14.0 ± 1.0
L x H line	8.04 ± 0.35	14.5 ± 0.5
Backcross on H line	n.a.	12.4 ± 1.4
Backcross on L line	n.a.	15.2 ± 1.4
Significance	n.s.	n.s.

n.a. – not applicable, the backcrosses were not yet available in 2004 progeny

n.s. – not significant ($P > 0.10$)

Gender interacted with sampling date for cube root transformed FWEC in Trial 1 and Trial 2 ($P < 0.05$). However, when trends for male and female animals were compared for progeny born in 2004 and 2005, it was clear that no consistent trend could be discerned (Fig. 4a and Fig. 4b). This type of interaction was also found in previous studies (Cloete *et al*. 2007), and could be ascribed to the fact that progeny are generally separated on gender before they reach sexual maturity. It is almost impossible to assure similar environmental conditions for the gender groups once they are separated, giving rise to the observed interactions.

The mean dag score of individuals in Trial 1 and Trial 2 was not affected by treatment with aloe (Table 3). In contrast, H line progeny consistently had lower ($P < 0.05$) dag scores than their contemporaries in the L line (Table 4). This line difference could possibly be associated with a reduced susceptibility to flystrike in the H line. The difference in dagginess between lines is more likely due to differences in wrinkliness than to a line difference in resistance to gastro-intestinal parasites since the animals in the H line tended to be less wrinkled than their L line contemporaries, while they excreted the same number of worm eggs. Scientific literature consistently reports on the negative genetic correlation between reproduction rate and wrinkle score (McGuirk 1969, Atkins 1980, Scobie *et al*. 2005a, b). The crossbred animals were generally intermediate in this respect as would have been expected.

Table 3. Overall least squares means (± s.e.) for dag score in animals treated with aloe or distilled water (Control) in Trial 1 and Trial 2.

Trial	**Treatment**		**Significance**
	Aloe	**Control**	
Trial 1 (2004 progeny)	2.33 ± 0.16	2.12 ± 0.15	n.s.
Trial 2 (2005 progeny)	2.22 ± 0.15	2.28 ± 0.16	n.s.

n.s. – not significant (*P* > 0.10)

Fig. 4a

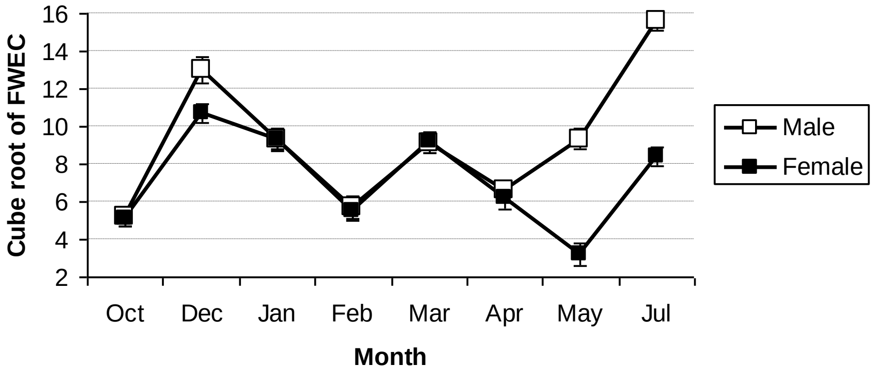

Fig. 4b

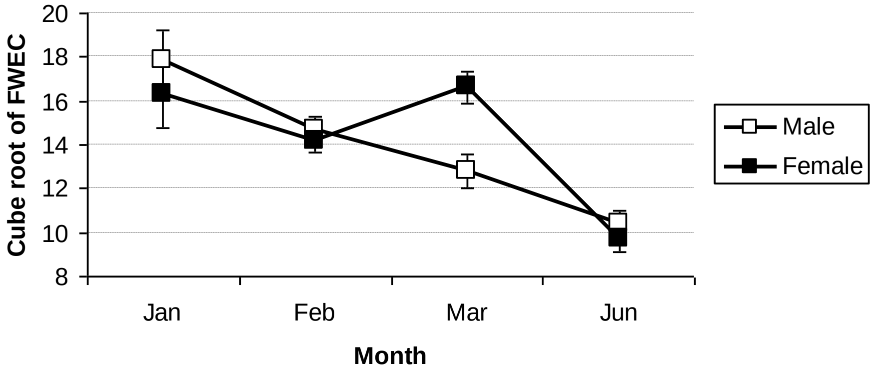

Fig. 4. The interaction of gender with sampling date for Trial 1 (Fig 4a) and Trial 2 (Fig 4b). Vertical lines about the means represent standard errors.

Table 4. Overall least squares means (± s.e.) for dag score in animals belonging to the respective selection lines in Trials 1 and Trial 2.

Selection line	**Trial 1**	**Trial 2**
H line	1.63 ± 0.09^{a}	1.73 ± 0.10^{a}
L line	2.86 ± 0.33^{c}	3.19 ± 0.25^{c}
H x L line	2.24 ± 0.19^{b}	$2.09 \pm 0.29^{a,b}$
L x H line	2.17 ± 0.21^{b}	2.43 ± 0.16^{b}
Backcross on H line	n.a.	$1.92 \pm 0.38^{a,b}$
Backcross on L line	n.a.	$2.12 \pm 0.33^{a,b}$
Significance	**	**

n.a. – not applicable, the backcrosses were not yet available in 2005

** – significant ($P < 0.01$)

^{a,b,c} – denotes significant differences in columns ($P < 0.05$)

CONCLUSIONS

Results from this study showed no reduction in the parasite burden when sheep were treated with Aloe, as was advocated in the introduction. A change in properties could have been caused by the heat treatment during the initial preparation process of the Aloe crystals, but such a deduction is speculative. Faecal worm egg count was not influenced by selection line, irrespective of treatment with Aloe.

There was an indication that the H line animals had less dags than the L line, with the crosses being intermediate as expected. These results seemed to be quite robust across years, suggesting that H line may be more resistant to breech strike than L line animals. Greeff and Karlsson (2009) reported a significant correlation between dag score and breech strike on the underlying scale. The results pertaining to dag score were also consistent with the outcome of a recent study by Scholtz *et al*. (2010) where it was found that mature ewes in the H line were less likely to contract breech strike compared to their L line contemporaries. Unfortunately flystrike could not be assessed in this study because of a lack of challenge.

The lack of effect of the Aloe treatment could be due to an inadequate way of administration or an ineffective dosage for the gastrointestinal challenge faced by the animals tested. Alternative administration methods or different dosages could therefore possibly be evaluated in future.

In the mean time strategies such as pasture management, selective breeding for less dags and lower FWEC, and other strategies reviewed in Chapter 2 should be considered in controlling blowfly strike.

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PART II

BREEDING OPTIONS

CHAPTER 5

INFLUENCE OF DIVERGENT SELECTION FOR REPRODUCTION ON THE OCCURRENCE OF BREECH STRIKE IN MATURE MERINO EWES

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INFLUENCE OF DIVERGENT SELECTION FOR REPRODUCTION ON THE OCCURRENCE OF BREECH STRIKE IN MATURE MERINO EWES

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ABSTRACT

Divergent selection resulted in Merino lines that differ markedly for reproduction. These lines were selected from the same base population from 1986 to 2009. Selection was initially based on maternal ranking values for reproduction in both ewe and ram progeny. The maternal ranking scores were augmented by breeding values from a single-trait repeatability model since 2003. The site and severity of flystrike were recorded for mature breeding ewes in the flock during 2007 to 2009. The following details were captured: animal number, site of the strike (body or breech) and the severity of the strike (1 – mild to 5 – severe). Breech strikes amounted to 92.1% of all strikes and this trend was consistent across years. High (H) line ewes were less likely ($P < 0.05$) than Low (L) line ewes to be suffering from breech strike. Ewes that suffered from breech strike during a reference year were more likely to be struck again during subsequent years, when compared with contemporaries not affected by breech strike in the reference year. When breech strike and body strike were assessed in a joint preliminary analysis, it seemed that body strike was generally more severe when diagnosed than breech strike. It was concluded that Merino sheep selected for improved reproduction for >20 years were less likely to be affected by breech strike than contemporaries selected for low reproduction.

Keywords: blowfly strike, frequency, repeated strike.

INTRODUCTION

Reproduction, defined as number or total weight of lambs weaned per breeding ewe per year (or over her lifetime), is considered to be the most important trait in the South African sheep industry (Olivier 1999). Indications against selection for reproduction are the composite nature of a trait defined as above, a low heritability, expression only in females, and recording at a relatively advanced age. Based on the economic value of reproduction, a divergent selection experiment was launched in the 1980s in South African Merino sheep (Cloete *et al*. 2004). This regime resulted in marked, but slightly asymmetric, genetic responses for reproduction, responses in the upward direction being approximately double those in the downward direction. In a recent review, Snowder and Fogarty (2009) argued that selection for a composite reproduction trait like number or weight of lambs weaned may result in responses in component traits being in balance with the available resource, while negative genetic correlations among component traits may also be negated. Benefits could also accrue in component traits where direct selection is unfeasible or difficult to achieve, such as embryo and lamb survival (Snowder and Fogarty 2009).

The impact of selection for reproduction on resistance to pathogens has so far not been studied in detail, as reflected by a paucity of genetic correlations between these traits in the review of Safari *et al*. (2005). However, some evidence was presented that a line selected for reproduction was less susceptible to infestation with the sheep body louse, *Bovicola ovis* than the line selected for a decreased reproduction (Cloete *et al*. 2003).

Flystrike is of major concern to sheep industries worldwide. Until recently breech strikes have mainly been controlled by chemical methods or the surgical procedure of mulesing. Potential problems with chemical methods as the leading form of defence against breech strike are pesticide resistance, occupational exposure to pesticides and accumulation of chemicals in the environment (Mortimer *et al.* 1998); chemical residues in wool fibres (Plant *et al*. 1999) and residues in wool by-products (James 1990). The method of chemical control is therefore under scrutiny especially in long wool sheep. With the change in social attitudes towards animal welfare (Plant 2006), surgical husbandry practices used in the management of sheep, in particular the mulesing practice has been targeted by animal welfare campaigners (Morris 2000, People for the Ethical Treatment of Animals 2004). The unacceptable short term animal welfare implications of mulesing have resulted in a decision by the sheep industry to have this procedure phased out in Australia by 2010 (Scobie *et al.* 1997, 1999, James 2006). Although managerial interventions (like crutching) still contribute to the prevention of breech strike in particular alternative strategies need to be reconsidered.

The impact of selection for reproduction upon a disease resistance trait like breech strike was investigated against this background. Bloodline differences in susceptibility to breech strike in mature Merino ewes that were divergently selected for overall reproduction rate were therefore investigated. The association of the incidence of breech strike in a reference year with breech strike in subsequent years was studied simultaneously.

MATERIALS AND METHODS

Animals, selection procedures and locations

Two lines of Merino sheep were divergently selected from the same base population from 1986 to 2009, using maternal ranking values for number of lambs reared per joining, as described by Cloete *et al*. (2004). These lines were derived from ewes descended from a Merino line selected for increased wool secondary:primary follicle (S:P) ratio (Heydenrych *et al*. 1984). In the progeny groups up to 2002, only the maternal phenotype was considered during the selection of individual replacement rams and ewes, and no additional information was used. Once selected, ewes remained in the breeding flock for at least five joinings, except for cases of death and teeth or udder malfunction. No selection on reproduction was therefore directed at the current flock. From the progeny group born in 2003, information on maternal ranking values used for selection was augmented by breeding values for number of lambs weaned per ewe joined in potential ram and ewe replacements. These breeding values were derived from a single-trait repeatability model, as described by Cloete *et al*. (2004). At the onset of the experiment, each line was represented by

~120 breeding ewes. The relatively poor reproduction in the L line resulted in breeding ewe numbers that decreased to below 40 (Table 2).

The progeny born in 1986 were sired by eight unselected rams from within the former S : P ratio line and formed the base year of the study. The 1987 progeny group was sired by five rams in each line selected on maternal ranking values from within the respective lines, a single ram of each line being carried across from 1986. The 1988 and 1989 progeny were sired by eight sires in each line (four per year) that were selected from the clean fleece weight selection line at Tygerhoek Research Farm. Most sires for the 1990 progeny group were selected from within lines (*n* = 3), but one sire in each line was selected from the control line maintained alongside. The study on selection for clean fleece weight is well documented (Heydenrych *et al*. 1984, Cloete *et al*. 1998). Initially, four to five rams represented each line. Until 1992, most of these rams were used for one breeding season only, the exception being the two rams that were carried across from 1986 to 1987. During later years, one to three rams in each line were carried over to the next year, to provide sire links across years. From the mid 1990s, the number of rams used in the H line was increased from four to six, whereas only two to four rams were used in the L line. It is conceded that the low number of sires in the L line is not optimal, and could introduce some bias. However, this arrangement was required to ensure that the number of ewes joined to each ram were not totally disproportional between lines, and also to maintain progeny groups of acceptable size. Ram replacements within selection lines were selected to represent all the sires present in their progeny group wherever possible. In cases when no suitable replacement for a specific ram was available within his progeny group, a candidate sire descended from the progeny group of another sire was selected on merit as replacement. More details of the selection process can be obtained from Cloete *et al*. (2004).

Since 2003, part of the breeding flock was subjected to reciprocal crossbreeding between the two lines, with the intention of forming a genetic resource population for possible future genomic projects (Naidoo *et al*. 2005). Crossbred progeny were available from the 2003 year of birth onwards, whereas backcrosses became available from 2005. When the data used for the present study were sourced during the 2007 to 2009 production years, information on backcross animals was still scant, and they were excluded from the study.

The resource flock studied was maintained at the Elsenburg Research Farm. The climate, pastures grown and management of the animals were adequately described by Cloete *et al*. (2004), while lambing and reproduction practices in the breeding flock were described by Cloete and Scholtz (1998). The climate at the experimental site is Mediterranean, with a winter lambing season (June-July) and pre-lamb shearing in May being practiced routinely. All animals were tail docked at the third palpable joint as lambs, while mature ewes were shorn in April-May and crutched in spring time (5 – 6 month’s wool growth) to reduce the probability of strikes over the festive season. The literature sources listed above may be consulted for additional information on these aspects.

Records

All ewes available for joining were inspected for defects of their teeth and udders, as well as general condition, during December of the previous year. Those ewes retained after this inspection were joined in single-sire groups during January-February and maintained until the commencement of lambing during June in the reference year. Site and severity of flystrike were recorded for mature breeding ewes in the flock during the summers from 2007 to 2009. Each strike was treated with a diazinon mixture after the following details were captured: animal number, site of the strike (body or breech) and severity of the strike. Severity of strike was defined by the diameter of the affected area scored on a scale between 1 (mild) and 5 (severe), whereby 1 ≤ 5 cm; 2 = 5-10 cm; 3 = 10-17 cm; 4 = 17-30 cm and 5 ≥30 cm. In one case recorded during 2009, a ewe was affected on both sites (breech and body) in a single severe strike. Information on the individual breeding ewes included selection line (H line, L line, H x L cross and L x H cross) and age (2 - 7+ years).

Statistical analyses

Initially, it was attempted to assess breech strike and body strike separately. However, it was later decided to confine the study to breech strike, as set out in the Results section. Only breech strike was thus expressed as frequencies for ewes belonging to the respective selection lines from 2007 to 2009. These frequencies were compared using standard Chi-square procedures (Van Ark 1990). When the Chi-square test for the whole 4 by 2 table (i.e. selection lines x breech strike category) indicated significant differences between frequencies we also conducted pairwise comparisons of rows. Because the information for such comparisons comes from the same 4 by 2 table and because this test probability has already been used, the test level was divided by the number of comparisons to be made. This ensures that the probability of making an incorrect inference remains at 5% for each pairwise comparison (also referred to as Type I error protection – Van Ark 1990). This process is referred to as the Bonferoni correction.

Second, the relation of breech strikes during a reference year was related to strikes during subsequent years in ewes that were available in both years. For this purpose, the ewes either sustaining breech strike or not in the reference year were used to compare frequencies of ewes that were struck or not in the subsequent year. Combinations that were considered included 168 ewes that were present in both 2007 and 2008, 117 ewes that were available in both 2007 and 2009, and 169 ewes that were available in both 2008 and 2009 (Table 3). As the observed frequencies were very low in some analyses, Fisher’s exact probability test (Van Ark 1990) for a 2 by 2 contingency table was also used for these comparisons. However, outcomes from the Chi-square test were consistent with those of the Fisher’s exact test, and only the former results were tabulated.

Third, the severity of breech strike and body strike was assessed for a total of 139 cases of flystrike that were recorded on 75 individual ewes between 2007 and 2009. Although the severity of strikes was assessed on a 5-point scale, the data was very skewed, with an excess of low scores. Selection lines were thus compared by Chi-square procedures, using categorised data. Scores of 1 were treated as one category, with scores exceeding 1 as the other category. The same basic procedure was used to compare the severity of breech strike with that of body strike.

RESULTS

Occurrence and distribution of breech and body strike

Of the overall 139 strikes recorded on 75 mature ewes, 127 were breech strikes, 11 body strikes and one ewe was struck both in the breech and on the body. Including the latter ewe, breech strikes thus amounted to 92.1% of all strikes. This trend was consistent across years (Table 1).

Flystrike was more prevalent during autumn (March-May) than during summer (December-February). Overall, 27.4% of 157 strikes (including the data recorded on backcross individuals in this case) were recorded in summer, compared with 72.6% in autumn (two-tailed Chi-square test = 32.11; degrees of freedom = 1; $P < 0.01$).

Table 1. The frequency of breech strikes in relation to all strikes that were recorded for the respective years of the study (2007 – 09).

The frequency of breech strike did not differ significantly between years ($P > 0.05$)

Year	Total number of strikes	Number of breech strikes	Frequency of breech strike[A]
2007	15	13	0.867
2008	75	69	0.920
2009	49	45	0.918

[A] A derived Chi-square value of 0.472 was computed. The critical Chi-square for 2 degrees of freedom was 5.99.

Frequency of strikes in the respective selection lines

During 2007 (when the overall prevalence of breech strike was low) small expected frequencies in the 4 (selection lines) by 2 (struck or not) table resulted in the Chi-square test having a weak discriminatory power (Table 2). When a 2 by 2 table was drawn up for the comparison of the two extremes (the H line and the L line), the Chi-square statistic suggested that there was a tendency for the H line to have a lower proportion of breech strikes than the L line (Chi-square = 3.30; degrees of freedom = 1; $P < 0.10$). Significant differences ($P < 0.05$) in the proportion of breech strikes between selection lines were evident during 2008 and 2009. H line ewes were less likely ($P < 0.05$) than L line ewes to be suffering from breech strike in both instances. First-cross individuals were generally intermediate, but L x H cross ewes had a lower ($P < 0.05$) prevalence of breech strikes than L line ewes in 2009, whereas H line ewes were less susceptible ($P < 0.05$) to breech strike than H x L cross ewes in both 2008 and 2009. The latter cross did not differ from the L line in either year (*P* > 0.10).

Table 2. The frequency of ewes suffering from breech strike in different selection lines (high, H or low, L) during three consecutive years (2007 - 09).

Critical Chi-square for 3 degrees of freedom ($P < 0.05$) = 7.815. Frequencies within year followed by different letters differ significantly ($P < 0.05$). n.e., small expected frequencies resulted in the 2007 analysis having a weak discriminatory power

Year and classification	**Genotype**				**Chi-square**
	H line	**L line**	**H x L cross**	**L x H cross**	
2007					
Number of ewes	131	31	30	29	
Breech strike	0.031	0.129	0.100	0.000	n.e.
2008					
Number of ewes	124	37	26	27	
Breech strike	0.081a	0.541c	0.269bc	0.111ab	41.8
2009					
Number of ewes	115	30	34	22	
Breech strike	0.052a	0.500b	0.324b	0.136ab	39.5

Repeated strike across years

Ewes that suffered from breech strike during a reference year were more likely to be struck again during subsequent years, when compared with contemporaries not affected by breech strike ($P < 0.05$; Table 3). The proportion of ewes being struck in subsequent years without being struck in a reference year ranged from 0.07 to 0.17. In contrast, proportions of ewes being struck again in subsequent years ranged from 0.45 to 0.82 in ewes suffering from breech strike in the reference year. These results appeared to be fairly robust across year combinations.

Severity of strikes

The proportion of ewes with the lowest possible score for breech strike (1) did not significantly differ between selection lines (Table 4). However, there was a suggestion ($P < 0.10$) for L line ewes to be more likely to have the lowest score. When breech strike and body strike were assessed in a joint preliminary analysis, it seemed that body strike was generally more severe when diagnosed than breech strike. Scores of 1 (indicative of a mild strike) was recorded in 71 out of 128 breech strike cases (0.555) whereas none out of 12 body strike cases (0.000) were categorised as mild (Chi-square = 11.38; degrees of freedom = 1; $P < 0.01$).

Table 3. Frequencies of breech strike during subsequent years in individuals that were either struck or not struck during a reference year.

Combination and frequency of ewes struck in the subsequent year	Status during reference year		Chi-square^{A}
	Struck	Not struck	
2007 for 2008			
Number of ewes	11	157	
Frequency of strikes during 2008	0.818	0.166	9.92
2007 for 2009			
Number of ewes	7	110	
Frequency of strikes during 2009	0.714	0.127	6.06
2008 for 2009			
Number of ewes	31	138	
Frequency of strikes during 2009	0.452	0.072	16.63

Table 4. Proportions of strikes categorised as 1 (mild) according to selection line (high, H or low, L) in affected Merino ewes.

Scores depicting the severity of breech strike ranged from 1 (mild) to 5 (severe). Critical Chi-square for 2 degrees of freedom ($P < 0.05$) = 5.99

Genotype	Number of observations	Proportion of ewes with score = 1
H line	21	0.429
L line	62	0.661
F1 crosses	24	0.467
Chi-square	-	5.62

DISCUSSION

Occurrence and distribution of breech and body strike

Breech strike is considered to be the most common form of blowfly strike (Seddon 1931, Belschner 1937, Watts *et al*. 1979, Murray and Wilkinson 1980, Raadsma and Rogan 1987) and this also held true for this study. The combination of long wool on the sheep during summer months when temperatures are high and humidity is relatively low (before the winter rains start in April-May) with the resulting absence of fleece rot and/or dermatophilosis; might be the reason for the low incidence of body strike. The ewes were shorn in May and were with short wool during the rainy winter period and therefore not as susceptible to fleece rot and body strike then either.

In a previous study at this locality, higher blowfly numbers were recorded from October to December and again during autumn (Scholtz *et al*. 2001). All ewes were crutched in September-October to give extra protection during the late spring/early summer (October-December) months when the animals were subjected to higher blowfly numbers. Apart from routine tail docking, no other preventative measures were taken against breech strike. Breech strike was more prevalent during March-May, possibly as the effects of crutching wore off with time. It is reasonable to expect that animals with 6 - 7 months of wool in the breech would be more susceptible than recently crutched individuals during a period when a rise in blowfly numbers is expected. Even with crutching being employed as a preventative measure for the festive season in December-January, the frequency of breech strike was still high enough to allow robust comparisons between selection lines.

Frequency of strikes in the respective selection lines

Overall, the frequency of breech strike was lower in the animals in the H line than in the L line; in other words, H line was less susceptible or more resistant to breech strike than L line contemporaries. Seeing that a tendency to this effect in 2007 (when the blowfly challenge was lower than in the other years) was supported by conclusive differences in both 2008 and 2009, the observed line difference could be regarded as fairly robust. The crosses were intermediate, as would have been expected. The consistency of these trends across years makes it reasonable to assume that divergent selection for reproduction has led to correlated changes in breech strike. It has to be conceded that no control line has been available for this experiment and that the effect of no selection is thus not known. It could be argued that selection in the downward direction (i.e. for more wrinkles) could have had an influence on the susceptibility to flystrike whereas selection in the upwards direction could arguably have had a smaller effect. However this argument does not seem to hold water if the increased resistance for breech strike resistance in the Wet and Dry line (Chapter 8) is considered. Furthermore, if it is considered that breeding values for dag score and breech fold score in Chapter 8 were roughly symmetric about zero, it seems unlikely that the response obtained was only brought about by an increased susceptibility to breech strike in the L line.

The difference in susceptibility to blowfly strike between the two selected lines can possibly, among others, be ascribed to earlier findings by Cloete *et al*. (2005) that hoggets in the H line are more plain-bodied than their contemporaries in the L line. Given that repeatability estimates of wrinkle scores on different body locations ranged from 0.50 to 0.62 (Hatcher *et al*. 2009), and that genetic correlations between yearling and adult records amounted to 0.76 for neck wrinkle score and 0.73 for body wrinkle score (Robinson *et al*. 2007), it can be safely assumed that this line difference is likely to persist into adulthood. Wrinkles in sheep have been implicated in the susceptibility of such sheep to blowfly strike since the early history of the sheep industry (Bull 1931, Seddon 1931, Seddon *et al*. 1931, Joint Blowfly Committee 1933). Moreover, Austin (1947) commented on the periodic objections by flock breeders to the poor “constitution” of heavily folded sheep. This objection probably stemmed from a general impression that increased fold development was associated with lower reproductive performance and an increased mortality (Dun 1964). Existing scientific literature (Dun 1961, Dun and Hamilton 1965, Fowler and Dun 1966, McGuirk 1969, Atkins 1980) confirms this impression by reporting on the negative phenotypic correlation between degree of skin wrinkling and fertility. Reproduction is of paramount importance in the South African sheep industry; where meat typically contributes largely to the income of wool farmers (Olivier 1999). This demand for meat has favoured the selection of plain-bodied animals, which have faster growth rates and higher lambing percentages (Poggenpoel and Van der Merwe 1987, Olivier and Cloete 1998, Cloete *et al*. 2005). Thus, divergent selection for reproduction in the resource flock used in this study resulted in the animals in the H line to become more plain-bodied than their contemporaries in the L line and therefore arguably less susceptible to blowfly strike.

Breed or line differences (as found in the present study) are often seen as indicative of genetic variation in a trait of interest. The present results thus support previous reports of significant genetic variation on the underlying scale in breech strike of Merinos (Greeff and Karlsson 2009).

Repeated strike across years

In general, susceptible animals in reference years were more likely to be affected in subsequent years than those not affected. Breech strike thus appeared to be repeatable in nature. This observation is in accordance with early findings reporting that the incidence of strike was broadly consistent with the degree of wrinkling in the breech area and that susceptibility to breech strike was repeatable with the same sheep being likely to be re-struck each season (Seddon 1931, Seddon *et al*. 1931, Joint Blowfly Committee 1933).

The repeatable nature of breech strike as well as the observed line differences suggest a possible genetic basis, as confirmed in recent analyses (Greeff and Karlsson 2009, Smith *et al*. 2009). Heritable and variable traits in animal breeding can be improved by either direct or indirect selection. The response to selection of most traits is maximised if a trait is selected for directly. Direct selection against flystrike is complicated when animals are raised and selected in low risk environments (Raadsma *et al*. 1987), while animal welfare also may be compromised under flywave conditions under natural challenge. Moreover, many Merinos are treated by some preventative measure (e.g. crutched or treated with chemicals) whereby they are protected from becoming infected (Greeff and Karlsson 2005), which may limit the expression of susceptibility to breech strike. Predisposing traits that make sheep less attractive to breech strike were thus considered as indirect selection criteria (Greeff and Karlsson 2005, 2009, Smith *et al*. 2009). Of five potential indirect selection criteria for breech strike investigated by Greeff and Karlsson (2009), dag score and urine stain were demonstrated to be most strongly genetically related on the underlying scale to the liability of sheep to contract breech strike.

Severity of strike

The average severity of breech strike was not very high, with more than 50% of recorded strikes being classified as mild. In contrast, none of the 12 recorded cases of body strike were categorised as mild. It could be argued that this was because of early diagnosis. The fact that the cases of body strike that were recorded were more severe than cases of breech strike could be related to the ease of detection of the two types of strike. Body strike (that is arguably more difficult to identify) may have been allowed to develop for longer periods when compared with breech strike.

CONCLUSIONS

Divergent selection for reproduction resulted in lines that differed markedly for their susceptibility to breech strike, with the line selected for reproduction being more resistant than the line selected against reproduction. This result suggests that selection for an increased reproduction rate will result in a decline in the frequency of breech strike as a correlated effect. Such a relationship stands to reason, as excessive skin folds have been conclusively linked to both a higher susceptibility to breech strike (Seddon 1931, Seddon *et al*. 1931, Joint Blowfly Committee 1933) as well as a reduced reproductive capacity (Dun 1964, McGuirk 1969, Atkins 1980).

Breed and/or line differences are often regarded as indicative of genetic variation in a specific trait. The present results therefore support recent reports of genetic variation in susceptibility to breech strike in Merino populations. It also lends impetus to a quest to breed an easily managed and robust genotype of sheep, which may be able to thrive under a variety of environmental conditions (Collins and Conington 2005).

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CHAPTER 6

GENETIC (CO)VARIANCES BETWEEN WRINKLE SCORE AND ABSENCE OF BREECH STRIKE IN MULESED AND UNMULESED MERINO SHEEP, USING A THRESHOLD-LINEAR MODEL

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GENETIC (CO)VARIANCES BETWEEN WRINKLE SCORE AND ABSENCE OF BREECH STRIKE IN MULESED AND UNMULESED MERINO SHEEP, USING A THRESHOLD MODEL

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ABSTRACT

Heritability estimates for, and genetic correlations among neck wrinkle score, body wrinkle score, breech wrinkle score and the absence of breech strike were determined on 2 918 16-month hoggets from a selection experiment with South African Merinos. Data were obtained from the lamb drops of 9 years between 1998 and 2007, born as the progeny of 247 sires and 1 250 dams. All progeny born until 2002 were subjected to the modified Mules operation as lambs (n = 1799). However, due to international pressure to phase out the Mules operation, animals from 2003 onwards were not mulesed (n = 1119). During both periods, the experimental animals were maintained in single flocks (separated on gender) after weaning. Progeny were subjected to visual appraisal of wrinkle scores (range) on the neck (1 - 6), body (1 - 5) and breech (1 - 6) at an age of ~ 16 months. The occurrence of blowfly strike in the breech area (breech strike) was recorded in all animals during the wool growth period of a year from shearing as weaners. Two four-trait animal models were fitted to obtain (co)variance components and ratios from the separate data sets with neck wrinkle score; body wrinkle score, breech wrinkle score and the absence of breech strike, all defined as threshold traits. Estimates of heritability for breech wrinkle score amounted to 0.27 and 0.45 for the mulesed and unmulesed groups, respectively. The absence of breech strike on the underlying scale was also heritable for the mulesed (0.33) and unmulesed (0.46) groups; translating to heritability estimates of 0.074 and 0.157, respectively, on the observed scale. The genetic correlations of wrinkle scores with breech strike were generally favourable, but significant only for neck wrinkle score (-0.57) and breech wrinkle score (-0.45) in the unmulesed group. It was concluded that South African Merino sheep would respond to direct selection against breech strike under conditions of adequate challenge. Based on results from unmulesed sheep, selection for plainer sheep is also expected to result in a favourable correlated response in breech strike.

Additional keywords: binomial distribution, blowfly strike, genetic correlation, heritability

INTRODUCTION

The Joint Blowfly Committee (1933) quote several early papers (Froggatt 1915, Froggatt and Froggatt 1916, 1917, 1918) in which it is noted that the production of a type of sheep with a wrinkled skin and dense wool was implicated in the susceptibility of such sheep to flystrike. Bull (1931) noted the following: ‘for many years, sheep breeders, probably more particularly those in South Australia have realised that the plain bodied sheep is less susceptible to attack by blowfly than the wrinkly sheep’. Early studies identified the importance of breech wrinkles in determining susceptibility to strike when Seddon (1931) showed that incidence of strike was broadly parallel to the degree of wrinkling in the breech area. Susceptibility to breech strike was also repeatable, the same sheep being likely to be re-struck each season (Seddon *et al*. 1931, Scholtz *et al*. 2010). However, very few estimates of (co)variance components of breech strike and wrinkle score are available. This state of affairs could possibly be related to the success of mulesing in limiting breech strike, as well as the sporadic and unpredictable nature of the problem.

Breeding sheep with reduced susceptibility was one of the earliest approaches to flystrike control and has continued to be an element of most Merino breeding programs (Seddon *et al*. 1931, Belschner 1937, Seddon and Belschner 1937, Atkins and McGuirk 1979, Raadsma and Rogan 1987, Mortimer 2001). In the past, the possibility of selection against flystrike has mainly centred round the reduction of body strike (Raadsma 1989, 1991a, b, c, Raadsma *et al*. 1992), for it was reasoned that it is relatively straightforward to control breech strike by using chemicals and the Mules operation, while external causes (like fighting) predispose rams to poll strike. However, social attitudes to animal welfare have changed dramatically in the past 20 years and in recent years surgical husbandry practices used in the management of sheep, in particular the mulesing practice, have been targeted by animal welfare campaigners (Morris 2000, People for the Ethical Treatment of Animals 2004) as having unacceptable short-term animal welfare implications and are in the process of being phased out in Australia (Scobie *et al.* 1997, 1999, Karlsson *et al*. 2001, James 2006, Lee and Fisher 2007, Peam 2007). Changing community standards on topics such as operator safety; environmental contamination and the development of insecticide resistance have resulted in over reliance on chemicals for the treatment of blowfly strike also coming under more intense public scrutiny (Tellam and Bowles 1997, Broughan and Wall 2006).

Mulesing is less widely practiced in South Africa (National Woolgrower's Association 2008), but it has been a common practice in the South Coast region of the Western Cape until recently. The climate in the Southern Coast region is considered to be conducive to the maintenance of high populations of the sheep blowfly compared with other regions in the Western Cape (Scholtz *et al*. 2000, 2001). Despite being mulesed, South African experimental animals were more likely to contract breech strike than body strike (Cloete *et al*. 2001). A higher frequency of breech strike compared with body strike in mulesed sheep has also been reported elsewhere (De Chaneet 1986). However, due to international pressure, the South African wool industry in collaboration with the National Society for the Prevention of Cruelty to Animals has announced the following: 'The practice of mulesing is cruel and causes pain and stress to the animal and is a contravention of the Animal Protection Act No. 71 of 1962*'* (National Woolgrower's Association 2009). Strategies for the prevention of blowfly strike in general thus need to be reconsidered, particularly for breech strike.

Genetic selection is an attractive solution to the breech strike problem, but there is not sufficient information currently available. In fact, the widespread practice of mulesing has probably hampered attempts to find a genetic solution. Furthermore, computing difficulties in calculating (co)variance ratios involving traits assessed on the binomial scale may also have contributed to this lack of estimates. However, software to allow the estimation of heritability and genetic correlations involving binomial and/or threshold traits and normally distributed traits are readily available (Misztal *et al*. 2002, Misztal 2008). Against this background, threshold models were used to estimate the heritability of neck wrinkle score, body wrinkle score, breech wrinkle score as well as the absence of breech strike on the underlying scale. Genetic and environmental correlations among these traits were estimated simultaneously.

MATERIALS AND METHODS

Animals, the environment and recordings

Performance records were obtained from four selection lines of Merino sheep maintained on the Tygerhoek Research Farm, near Riviersonderend in the Western Cape Province of South Africa, between 1998 and 2007. The climate at this site is Mediterranean, and key climate data and managerial inputs were reported by Cloete *et al*. (1998). Lines that were involved in the present study were selected for an increased clean fleece weight (Clean Fleece Weight line), against reproductive failure (referred to as Wet and Dry line) and for reduced fibre diameter (Fine Wool line). The Wet and Dry line was discontinued after 2002. A Control line, where no directed selection was practised, was maintained together with the selection lines. More information with regard to these selection lines can be found in the literature (Cloete *et al*. 1998, 2001).

Ewes in these lines were mated during October-November to lamb during March-April of the following year, throughout the period of data recording. Data were available on a total of 2 918 animals, born from 1998 to 2007 as the progeny of 247 sires and 1 250 dams. No flystrike or wrinkle score data were recorded in the progeny group of 2004, and data for this year were excluded from the analysis.

All progeny born were tail docked at the third palpable joint before they were four weeks old. Lambs were shorn as weaners in August-September of each year, crutched in February and shorn again as hoggets in August-September of the following year when they had a year's wool growth. Progeny born until 2002 were subjected to the Modified Mules operation, as described by Morley and Johnstone (1984), as lambs. Due to international pressure on phasing out mulesing, this practice was terminated on the Research Farm in the 2003 progeny group. Two separate data sets were thus available, namely 1799 records obtained on hoggets that were subjected to the Mules operation up to 2002, and 1119 hoggets where the operation was not practised since 2003. Sires and dams represented were respectively 165 and 819 in mulesed hoggets and 83 and 555 in unmulesed hoggets. During both periods, weaners were maintained in single flocks (separated on gender) after weaning. All progeny were subjected to visual appraisal of wrinkle scores on the neck, body and breech at an age of ~ 16 months (Dun and Hamilton 1965). Using photographic standards, low scores were allocated to the plainest sheep, while those with the most wrinkles were awarded the highest scores. The range of scores was 1 - 6 on the neck, 1 - 5 on the body and 1 - 6 on the breech (Table 1). It is notable that, while the direction of the scores was similar to those of Mortimer *et al*. (2009), the number of categories for neck wrinkle score was 6 as compared to 5 in the latter study. The absence of blowfly strike in the breech area (absence of breech strike) was recorded in all animals during the wool growth period of a year between weaner and hogget shearing (Cloete *et al*. 2001). These records were confirmed at hogget shearing in August-September, where needed. Routine management for the prevention of flystrike included the strategic treatment of all short-wool animals with cyromazine (Vetrazin, Novartis Animal Health, Isando, South Africa) during November-December over the Christmas holiday season. Spot treatment with a product containing chlorfenvinphos (30%) and esfenvalerate (2.5%) (Sumiplus, Bayer Animal Health, Isando, South Africa) was administered to those sheep suffering from breech strike after the strike has been recorded. Individual sheep were recorded as either having contracted breech strike or not, i.e. the distribution was binomial.

The bulk of the data recorded for this study was done before the formation of a formal Departmental Ethical Committee for Research on Animals (DECRA) in 2004. Based on information supplied to DECRA, post facto ethical approval was granted for the study (DECRA reference number R09/22).

Statistical analyses

Two four-trait animal models were fitted to the separate data sets, with neck wrinkle score, body wrinkle score, breech wrinkle score and the absence of breech strike as the dependent variables. Various analyses involving wrinkle scores as linear or threshold traits were conducted. For the analyses that were presented, neck wrinkle score was defined as a threshold trait with six categories and five thresholds, body wrinkle score as a threshold trait with five categories and four thresholds, and breech wrinkle score as a threshold trait with six categories and five thresholds. Breech strike was defined as a binary trait with two categories (1 for hoggets that experienced breech strike and 2 for those not struck). As higher scores were awarded to those animals not suffering from breech strike, the trait analysed was defined as absence of breech strike. The fixed effects that were fitted included year of birth (1998 – 2002 for mulesed sheep and 2003 – 2007 for unmulesed sheep), gender (male and female) and birth type (single and multiple). Preliminary analyses indicated that neither trait was affected by age of dam, which was excluded as a fixed effect. Selection line was also included in preliminary analyses. However, the derived genetic parameters, and conclusions derived from them, were fairly robust across analyses and selection line was therefore also excluded from the final analyses as a fixed effect. The equation for the four-trait models fitted to the two data sets was the following:

$$y_{ijkl} = yr_{ij} + s_{ik} + bt_{il} + a_{im} + e_{ijklmn} \qquad (1)$$

In this model, *y* was a vector of observations for neck wrinkle score, body wrinkle score, breech wrinkle score and for underlying values for absence of breech strike; *i* was indicative of the respective traits (i = 4), yr_{ij} was the fixed effect of year for the i'th trait, s_{il} was the fixed effect gender for the i'th trait, bt_{il} was the fixed effect birth type for the i'th trait, a_{im} was the additive genetic effect of the n'th animal for the i'th trait, and e_{ijklm} was the vector of randomly distributed residual effects.

The software used was THRGIBBS1F90 (Misztal *et al*. 2002, Misztal 2008). This software is suitable for the estimation of variance components and genetic parameters in threshold-linear animal mixed models for any combination of categorical and continuous traits. The program POSTGIBBSF90 was used for Post Gibbs analysis (Misztal *et al*. 2002). The software allows for the estimation of genetic and environmental (co)variance components, to enable the calculation of genetic parameters for traits of interest. Heritability estimates were transformed to the observed scale by the following equation (Dempster and Lerner 1950):

$$h^2_{\text{pa}} = \bar{z}^2 h^2_x / \bar{p}\,\bar{q} \qquad (2)$$

where h^2_{x} is the heritability on the underlying normal scale, h^2_{pa} is the heritability on the observable binomial scale, $\bar{p}\,\bar{q}$ is the total variance and $\bar{z}^2 h^2_{\text{x}}$ is the additive genetic variance on the p scale.

A single chain of 300 000 cycles were run, with the first 100 000 cycles used as the burn-in period. When compared to the analyses of Donoghue *et al*. (2004) this could be considered as an extremely conservative approach. When the sampled values were plotted against the iterations, a stationary stage could be confirmed at this stage by graphical inspection. Every 10th sample was stored after 100 000 iterations, giving a total of 20 000 samples for the computation of posterior means, posterior standard deviations as well as 95% highest posterior density (HPD) confidence intervals. Point estimates were calculated as the posterior mean of the specific variance component, using the results from the final 200 000 samples as set out above. Direct genetic and environmental (residual) correlations were derived from these analyses.

Animal solutions were obtained from these analyses and averaged within birth years for the respective selection lines to obtain genetic trends. These yearly averages within birth years were regressed on birth year where appropriate, using standard linear regression techniques.

RESULTS

Descriptive statistics

Of the 1 799 animals subjected to the Mules operation during 1998 to 2002, 109 were recorded to have suffered from breech strike (a proportion of 0.061). Correspondingly, a proportion of 0.095 of the 1 119 animals not subjected to the Mules operation suffered from breech strike. The frequency of breech strike was variable between years, ranging from 0.003 in the progeny group of 2001 to 0.116 in the progeny group of 1998 in the data set comprising of animals subjected to the Mules operation (Chi-square = 51.24; d.f. = 4; *P* < 0.01). The corresponding range in the data set comprising of animals not subjected to the Mules operation were from 0.021 in the 2006 progeny group to 0.261 in the hoggets born in 2007 (Chi-square = 78.72; d.f. = 3; *P* < 0.01). Gender affected the incidence of breech strike in mulesed hoggets (0.085 in rams versus 0.042 in ewes; Chi-square = 14.07; d.f. = 1; *P* < 0.01) but not in unmulesed hoggets (0.109 in rams versus 0.082 in ewes; Chi-square = 2.08; d.f. = 1; *P* > 0.10). The incidence of breech strike was independent of birth type in mulesed hoggets (0.063 in singles versus 0.058 in multiples; Chi-square = 0.14; d.f. = 1; *P* > 0.50), but multiples were less likely to be struck than singles in unmulesed hoggets (0.120 in singles versus 0.068 in multiples; Chi-square = 8.32; d.f. = 1; *P* < 0.01). Breech strike was not affected by dam age in either data set.

Descriptive statistics for the traits under consideration are provided in Table 1. The coefficients of variation calculated from the data in Table 1 ranged from 25.8 to 33.5% for the respective wrinkle scores of sheep subjected to the Mules operation and from 23.4 to 24.8% for sheep not subjected to the Mules operation. The distribution of these data did not deviate from normality, yet it was considered as threshold traits in the final analysis, to get an indication of the proximity of the thresholds. Apart from the first two thresholds, which were set to 0 and 1, respective means (± posterior s.d.) for the remaining thresholds for neck wrinkle score were 1.8 ± 0.1, 2.6 ± 0.1 and 3.2 ± 0.2 for mulesed sheep and 2.1 ± 0.1, 3.0 ± 0.2 and 3.7 ± 0.3 for unmulesed sheep. Corresponding values for body wrinkle score were 2.2 ± 0.1 and 3.1 ± 0.1 for mulesed sheep and 2.5 ± 0.1 and 3.6 ± 0.2 for unmulesed sheep. Comparable thresholds for breech wrinkle score were 2.2 ± 0.1, 2.9 ± 0.1 and 3.5 ± 0.2 for mulesed hoggets and 2.3 ± 0.1, 3.1 ± 0.2 and 3.8 ± 0.4 for unmulesed hoggets. Respective frequencies of 0.94 and 0.91 of mulesed and unmulesed hoggets were not affected by breech strike.

Genetic parameters

Posterior distributions for the genetic variance components for breech strike on the underlying scale in the presence or absence of the Mules operation are presented in Fig. 1. The genetic variance components were significant in both instances, as reflected by 95% confidence limits for the HPD excluding zero. Numeric values for 95% HPD confidence limits were 0.03 - 0.96 for hoggets subjected to the Mules operation, and 0.01 - 1.69 for those left without the Mules operation. Although posterior distributions from the two datasets were largely overlapping, it is evident that the posterior mean used for the derivation of heritability would be higher in absolute terms in hoggets that were not subjected to the Mules operation as lambs.

Table 1. Basic descriptive statistics for the crude data analysed for Merino hoggets subjected to the Mules operation (1998 to 2002) or hoggets not subjected to the Mules operation (2003 to 2007, excluding 2004).

The absence of breech strike is termed as 'absence of strike'. n.a., the distribution of breech strike is incidence related and values for skewness and kurtosis are thus not given

Trait	**Mean ± s.d.**	**Range**	**Skewness**	**Kurtosis**
Hoggets subjected to the Mules operation (n = 1799)				
Neck wrinkle score	3.37 ± 0.92	1 – 6	0.30	-0.08
Body wrinkle score	2.60 ± 0.87	1 – 5	0.07	0.06
Breech wrinkle score	2.83 ± 0.73	1 – 6	0.44	1.43
Absence of strike	1.94 ± 0.24	1 – 2	n.a.	n.a.
Hoggets not subjected to the Mules operation (n = 1119)				
Neck wrinkle score	3.59 ± 0.84	1 – 6	0.39	0.23
Body wrinkle score	3.19 ± 0.79	1 – 5	0.36	0.49
Breech wrinkle score	3.17 ± 0.77	1 – 6	0.70	1.37
Absence of strike	1.91 ± 0.29	1 – 2	n.a.	n.a.

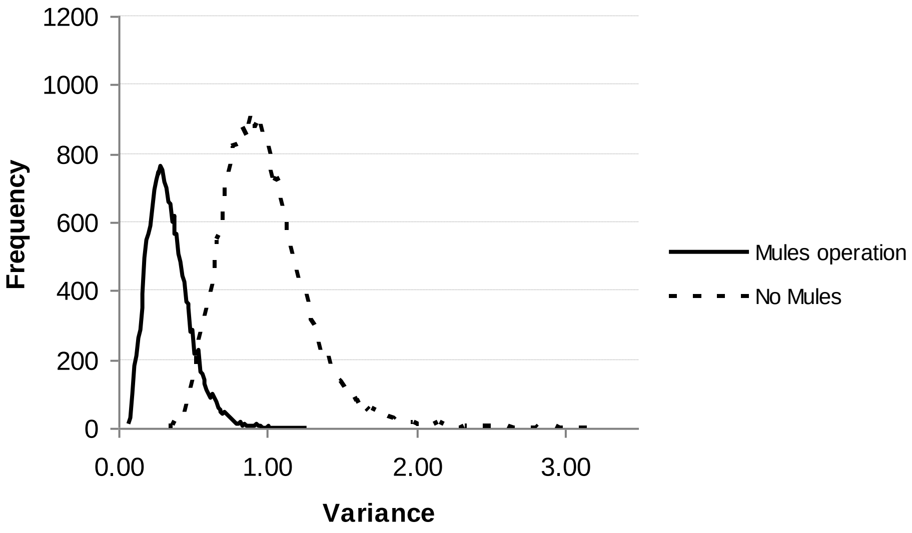

Fig. 1. Posterior distributions for the genetic variance components of breech strike in Merino hoggets subjected to the Mules operation (1998 - 2002) or not subjected to the Mules operation (2003 - 2007, excluding 2004).

Estimates of heritability (h^2) ranged from 0.33 to 0.42 for neck wrinkle score, 0.30 to 0.32 for body wrinkle score, 0.28 to 0.45 for breech wrinkle score and to 0.33 to 0.46 for absence of breech strike (Table 2). It is noteworthy that the h^2 for breech wrinkle score in sheep left without the Mules operation was substantially higher in absolute terms than in those that were subjected to the Mules operation. However, breech wrinkle score was still moderately heritable in the latter group, in spite of the fact that breech wrinkle scores were arguably altered by the modified Mules operation that was applied. The absolute magnitude of the h^2 of absence of breech strike was accordingly higher in absolute terms in sheep that were subjected to the Mules operation, as depicted by posterior distributions in Fig. 1. With the derived standard errors, this difference could not be considered as significant. It is noteworthy that the h^2 estimates for the absence of breech strike were fairly robust irrespective of the terms included as fixed effects in the analyses. Estimates of h^2 were 0.25 ± 0.11 for mulesed hoggets and 0.49 ± 0.16 for unmulesed hoggets when fold scores were treated as linear traits. The inclusion of selection line as an additional fixed effect resulted in respective h^2 estimates of 0.34 ± 0.15 and 0.51 ± 0.22, while estimates of 0.33 ± 0.15 and 0.51 ± 0.25 were obtained when year of birth was included as a sole fixed effect.

Table 2. Variance components, posterior standard deviations (PSD) and variance ratios (± s.e.) for neck, body and breech wrinkle score, as well as for the absence of breech flystrike (absence of strike) on the underlying scale in Merino hoggets subjected to the Mules operation (1998 to 2002) or hoggets not subjected to the Mules operation (2003 to 2007, excluding 2004).

Trait	**Direct additive variance**		**Residual variance**		**h^2 ± s.e.**
	Mean	**PSD**	**Mean**	**PSD**	
Hoggets subjected to the Mules operation (n = 1799)					
Neck wrinkle score	0.139	0.030	0.262	0.037	0.33 ± 0.08
Body wrinkle score	0.186	0.035	0.389	0.040	0.32 ± 0.06
Breech wrinkle score	0.116	0.022	0.292	0.031	0.28 ± 0.06
Absence of strike	0.494	0.239	1.006	0.048	0.33 ± 0.16
Hoggets not subjected to the Mules operation (n = 1119)					
Neck wrinkle score	0.200	0.059	0.279	0.067	0.42 ± 0.12
Body wrinkle score	0.196	0.065	0.453	0.081	0.30 ± 0.10
Breech wrinkle score	0.258	0.074	0.314	0.070	0.45 ± 0.13
Absence of strike	0.846	0.430	1.008	0.063	0.46 ± 0.23

The genetic correlation among wrinkle score on different body parts were high, and ranged from 0.80 to 0.99 in hoggets subjected to the Mules operation and between 0.89 to 0.97 in hoggets that were not subjected to the Mules operation (Table 3). The absolute direction of the genetic correlations of wrinkle scores with the absence of breech strike were consistently negative, indicating that low wrinkle scores were associated with a reduced susceptibility to breech strike. However, it only reached significance in the analysis involving those hoggets not subjected to the Mules operation. The genetic correlations of body and breech wrinkle scores with the absence of breech strike were close to zero in hoggets subjected to the Mules operation. All genetic correlations of wrinkle scores with the absence of breech strike were substantially higher in absolute terms for those animals where the Mules operation was no longer practised.

Table 3. Genetic covariance components, posterior standard deviations (PSD) and genetic correlations (± s.e.) for neck wrinkle score, body wrinkle score, breech wrinkle score and the absence of breech flystrike (absence of strike) in Merino hoggets.

Trait	Correlated trait	Covariance component	PSD	Correlation ± s.e.
Hoggets subjected to the Mules operation (n = 1799)				
Neck wrinkle score	Body wrinkle score	0.135	0.029	0.87 ± 0.19
	Breech wrinkle score	0.098	0.029	0.80 ± 0.18
	Absence of strike	-0.051	0.056	-0.20 ± 0.22
Body wrinkle score	Breech wrinkle score	0.145	0.028	0.99 ± 0.19
	Absence of strike	-0.008	0.061	-0.03 ± 0.20
Breech wrinkle score	Absence of strike	-0.007	0.048	-0.03 ± 0.20
Hoggets not subjected to the Mules operation (n = 1119)				
Neck wrinkle score	Body wrinkle score	0.193	0.059	0.97 ± 0.30
	Breech wrinkle score	0.203	0.050	0.89 ± 0.22
	Absence of strike	-0.235	0.108	-0.57 ± 0.26
Body wrinkle score	Breech wrinkle score	0.211	0.052	0.94 ± 0.23
	Absence of strike	-0.189	0.096	-0.46 ± 0.24
Breech wrinkle score	Absence of strike	-0.203	0.099	-0.45 ± 0.21

As an example, the favourable (negative) posterior distribution for the genetic covariance between breech wrinkle score and the absence of breech strike is presented in Fig. 2. HPD confidence limits at the 95% probability level were -0.40 and -0.02 for this covariance. In contrast, the covariance between breech wrinkle score and breech strike was almost perfectly symmetric about zero (95% HPD confidence limits of -0.10 and 0.09) for those hoggets that were subjected to the Mules operation during the 1998 to 2002 period.

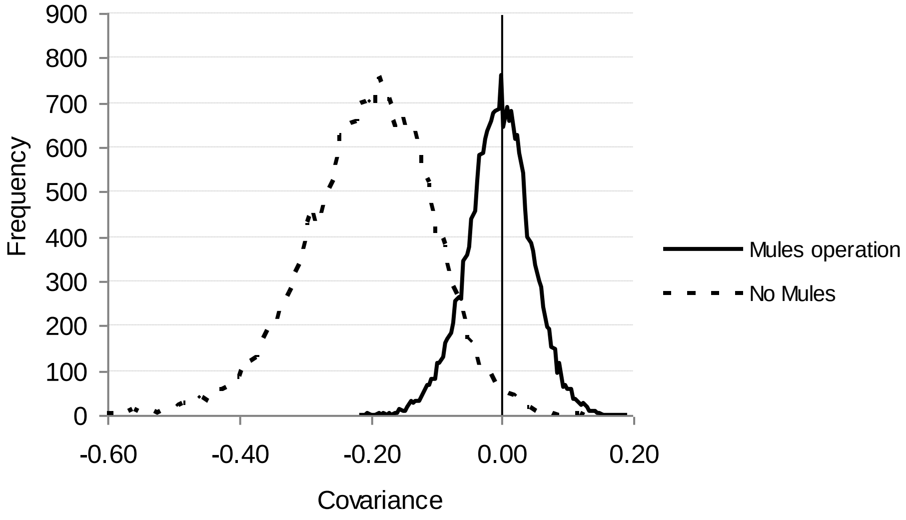

Fig. 2. Posterior distributions for the genetic covariance components between breech wrinkle score and breech strike in Merino hoggets subjected to the Mules operation (1998 to 2002) or not subjected to the Mules operation (2003 to 2007, excluding 2004).

The environmental correlations between wrinkle score on different body parts were generally high and significant (ranging from 0.58 to 0.73 in hoggets subjected to the Mules operation and from 0.56 to 0.74 in those not subjected to the Mules operation (Table 4). Wrinkle development was largely uncorrelated with the absence of breech strike on the environmental level in both data sets. The focus of this study was not to assess differences in averaged breeding values between lines. However, it was noteworthy that there was strong evidence of a linear incline in the absence of breech strike amounting to 0.122 ± 0.023 per annum ($P < 0.05$) in the Wet and Dry line from 1998 to 2002. No concomitant genetic trends were evident for fold scores.

Table 4. Environmental covariance components, posterior standard deviations (PSD) and environmental correlations (± s.e.) for neck wrinkle score, body wrinkle score, breech wrinkle score and the absence of breech flystrike (absence of strike) in Merino hoggets.

Trait	Correlated trait	Covariance component	PSD	Correlation ± s.e.
Hoggets subjected to the Mules operation (n = 1799)				
Neck wrinkle score	Body wrinkle score	0.233	0.027	0.73 ± 0.10
	Breech wrinkle score	0.160	0.022	0.58 ± 0.07
	Absence of strike	0.011	0.054	0.02 ± 0.10
Body wrinkle score	Breech wrinkle score	0.203	0.025	0.60 ± 0.07
	Absence of strike	-0.026	0.062	-0.04 ± 0.10
Breech wrinkle score	Absence of strike	-0.056	0.050	-0.10 ± 0.09
Hoggets not subjected to the Mules operation (n = 1119)				
Neck wrinkle score	Body wrinkle score	0.263	0.049	0.74 ± 0.17
	Breech wrinkle score	0.165	0.037	0.56 ± 0.10
	Absence of strike	0.056	0.82	0.11 ± 0.15
Body wrinkle score	Breech wrinkle score	0.261	0.050	0.69 ± 0.13
	Absence of strike	-0.059	0.086	-0.09 ± 0.13
Breech wrinkle score	Absence of strike	-0.063	0.078	-0.11 ± 0.14

DISCUSSION

Genetic parameters

Heritability estimates for neck wrinkle score were moderately high for both the mulesed (0.33) and unmulesed (0.42) groups (Table 2) and compares well with heritability estimates of 0.27 and 0.42 from the respective studies by Lewer *et al*. (1995) and Mortimer *et al*. (2009). The h^2 estimates for body wrinkle score for mulesed and unmulesed hoggets ranged between 0.30 and 0.32 and are higher than the heritability estimate of 0.15 reported by Lewer *et al*. (1995), comparable to an estimate of 0.25 reported by Smith *et al*. (2009), although it is somewhat lower than the estimate of 0.42 reported by Mortimer *et al*. (2009). Few h^2 estimates specifically for breech wrinkle score are available in the literature. Lewer *et al*. (1995) estimated h^2 at 0.19 for breech wrinkle score, while Raadsma and Rogan (1987) cited a range of h^2 estimates of 0.4 - 0.5 with the source given as McGuirk (unpubl. data). More recent h^2 estimates for breech wrinkle score were 0.45 (Greeff and

Karlsson 2009) and 0.36 (Smith *et al*. 2009). Comparable estimates of h^2 from this study ranged from 0.28 for hoggets subjected to mulesing to 0.45 for unmulesed hoggets, which is in accordance with the cited literature. Results from this and other studies suggest that the h^2 of wrinkle scores on the respective body regions are moderate to high, indicating that substantial gains could be made by purposeful selection. This is in accordance with the review of Turner (1977), which suggested that, with the high h^2 of wrinkle score, genetic change towards plainer–bodied animals should be easy to achieve.

Breech strike on the underlying scale was heritable for mulesed (0.33) and unmulesed (0.46) hoggets. It should be emphasised that some preventative treatment (cyromazine and crutching) was applied to the experimental animals. These preventative measures would have resulted in protection against breech strike for up to 12-odd weeks after application. Strikes occurring in the remainder of the period, albeit sporadic in some years, were sufficient for genetic variation to be detected. This opens up the possibility of reducing breech strike by direct selection, thereby reducing reliance on chemicals for prevention and for spot treatment of strikes, as well as the need for the Mules operation. The only comparable estimate for the h^2 of breech strike on the underlying scale amounted to 0.54 (Greeff and Karlsson 2009). Smith *et al*. (2009) reported a linear model h^2 of 0.32 for number of breech strikes within a season. Our estimates were consistent with these literature estimates.

The genetic correlations between neck wrinkle score and body wrinkle score for the mulesed (0.87) and unmulesed (0.97) groups approached unity, suggesting that the traits were determined by largely the same set of genes (Table 3). Mortimer *et al*. (2009) accordingly reported a very high positive genetic correlation between neck wrinkle and body wrinkle score (0.92). This estimate is consistent with earlier estimates exceeding 0.90 (Beattie 1962, Mortimer and Atkins 1993, Lewer *et al*. 1995), confirming these traits to be genetically very similar.

The genetic correlation between neck and breech wrinkle score for the mulesed (0.80) and unmulesed (0.89) hoggets in this study (Table 3) is also in accordance with the literature. Studies done by Jackson and James (1970) and Lewer *et al*. (1995) reported estimates of 1.00 and 0.91 for the genetic correlation between wrinkles when scored on the neck and the breech. The genetic correlation between body and breech wrinkle scores in this study was high (Table 3), comparing favourably to an estimate of 0.99 reported by Jackson and James (1970). Lewer *et al*. (1995), however, reported a somewhat lower genetic correlation of 0.50.

The negative genetic correlation of neck and breech wrinkle scores with the absence of breech strike in the current report suggests that more wrinkly animals (with higher scores) are more likely to suffer from breech strike than their plainer contemporaries. The direction of this correlation is in accordance with results from early studies (Seddon 1931, Seddon *et al*. 1931, Joint Blowfly Committee 1933, MacKerras 1936) wherein ewes were classified on the basis of the number and location of caudal wrinkles in the breech area into relatively insusceptible (Class A), moderately susceptible (Class B) and definitely susceptible (Class C) types. It was reported that the relative incidence of breech strike was significantly less in the 'less wrinkly' classes. However, these results were not condensed into a genetic correlation between wrinkle development and susceptibility or resistance to breech strike.

The occurrence of flystrike depends on weather conditions, which are often transient and unpredictable. Selection gains under such conditions are often difficult to achieve, even without the added complication of breech strike being evaluated on the binomial scale. The heritability estimates for absence of breech strike (0.33 in mulesed hoggets and 0.46 in unmulesed hoggets) translates to 0.074 and 0.157, respectively, on the observed scale. Being significantly different from zero, these values indicate prospects for direct selection to be successful under conditions of adequate challenge. Selection responses may, however, be slow under conditions of suboptimal challenge. The unpredictability of breech strike, the widespread use of prophylactic treatments such as jetting and crutching, as well as animal welfare concerns under adequate challenge conditions, adds to arguments for indirect selection instead of direct selection (Scholtz *et al*. 2010). In this respect, selection for plainer hoggets seems likely to play a role in lowering breech strike. This was the case only in unmulesed hoggets, where the genetic correlation with absence of breech strike on the underlying scale amounted to -0.45 (translating to -0.20 on the observed scale). No gains were likely in mulesed hoggets, where the corresponding genetic correlation was effectively zero. The only comparable genetic correlation between breech strike and breech fold score on the underlying scale was an estimate of 0.23 in the study of Greeff and Karlsson (2009). The difference in sign between estimates stems from the absence of breech strike being analysed in the present study, whereas Greeff and Karlsson (2009) studied the incidence of breech strike.

Breech wrinkle score is not the only indicator trait implicated to be of value in the control of breech strike. Aspects like bare breeches (Scobie *et al*. 2002, Hebart *et al*. 2006, James 2006, Scobie *et al*. 2008, Greeff and Karlsson 2009) and a reduction of dags in the breech area (James 2006, Scobie *et al*. 2007, Greeff and Karlsson 2009) may also play a role in the reduction of breech strike in Merinos and warrants further research. Of the indicator traits analysed, significant genetic correlations with breech strike were reported for dag score (0.86) and urine stain (0.53) (Greeff and Karlsson 2009).

The linear incline in breeding values on the underlying scale for breech strike in the Wet and Dry line suggest that selection for a higher reproduction rate may lead to animals becoming more resistant to breech strike. Even though the Modified Mules operation was used on the Wet and Dry line hoggets they appeared to become less susceptible to breech strike with time. Given that Atkins (1980) reported that wrinkly sheep had a lower reproduction than plainer contemporaries, it seems reasonable to contend that highly reproductive sheep are plainer which in turn would lead to a reduced incidence of breech strike. However, the genetic trend in this study could not be conclusively related to wrinkle scores, maybe because of the Mules operation performed on the hoggets in question. Further research is needed to better understand these results. However, the observed genetic trend in the Wet and Dry line supports a report by Scholtz *et al*. (2010) that breech strike was markedly reduced in a Merino line selected for an increased reproduction compared with a contemporary line selected against reproduction. There thus seems to be evidence accruing that selection for an improved reproduction will reduce the susceptibility of Merino sheep to breech strike.

CONCLUSIONS

The present study suggests that breech strike on the underlying scale is partly under genetic control. Heritability estimates on the observed scale amounted to 0.074 for mulesed hoggets to 0.157 for unmulesed hoggets. Selection could thus be used to select animals that are less susceptible to breech strike, provided that adequate blowfly challenge prevails. Because of several reasons listed above, direct selection may only result in relatively slow genetic change.

Given the complexity of direct selection against breech strike, attention should be given to the possibility of acquiring genetic change by indirect selection. In this study there was evidence that selection against skin wrinkle could play a role in reducing the susceptibility of sheep to breech strike in unmulesed sheep only. Considering the phasing out of the Mules operation in sheep producing countries, this is a positive result. More such indicator traits, which are not as dependent on climate as breech strike, should be identified and combined in a selection index. Apart from wrinkle scores, traits like dag scores, crutch scores, bare breeches and wool conformation may also play an important role. The significant genetic variation for absence of breech strike remaining in mulesed sheep in the present study hints at traits not associated with wrinkles and bare breech, (which are arguably being strived for during the Mules operation) also being important in breech strike resistance genetics. As breech strike is associated with large production, financial and welfare losses, indirect selection may become an important component of an integrated blowfly control strategy. Further research is required to elucidate the specific role of individual indicator traits in integrated blowfly control.

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CHAPTER 7

PRELIMINARY RESULTS ON THE BREECH AND COVER SCORES OF MERINO EWES DIVERGENTLY SELECTED FOR THEIR ABILITY TO REAR MULTIPLE OFFSPRING

Short communication

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ABSTRACT

Divergent selection for reproduction from the same base population since 1986 resulted in Merino lines that differ markedly for reproduction rate. Subjective scores for dags, breech cover, crutch cover and belly quality (with score 1 lowest and 5 highest) were recorded for mature and maiden ewes of these lines. Ewes in the High (H) line rearing 1+ lamb had lower breech cover, crutch cover and belly quality scores than all the other groups ($P < 0.05$). H line ewes rearing no lambs and Low (L) line ewes rearing 1+ lamb were generally intermediate, with L line ewes rearing no lambs having the highest scores ($P < 0.05$) for these three traits. Expressed relative to H line performance, overall breech cover scores were 22% higher in L line ewes than in H line ewes. Corresponding selection line differences amounted to 41% for crutch cover score, and 27% for belly quality scores. In maiden ewes, where scores were not complicated by reproduction, scores were higher ($P < 0.01$) in the L line, with the exception of belly quality score, where only a tendency was found ($P = 0.07$). Expressed relative to mean H line performance, these differences amounted to 63% for dag score, 34% for breech cover score and 33% for crutch cover score. With the exception of dag score, subjective scores allocated to ewes rearing no lambs were higher than those of ewes rearing 1+ lamb ($P < 0.01$). These differences amounted to 35% for breech cover score, 49% for crutch cover score and 47% for belly quality score. The bellies of ewes that reared 1+ lamb were more likely to be hairy than those of ewes that failed to rear a lamb (43/93 = 0.462 versus 8/33 = 0.242; Chi-square = 4.02; degrees of freedom = 1; $P < 0.05$). It was concluded that selection for improved reproduction in Merinos will result in favourable breech and crutch characteristics and a reduced reliance on mulesing.

Keywords: blowfly strike, breech cover, crutch cover, dags

INTRODUCTION

Selective breeding for reproduction has been advocated in South Africa since reproduction is of paramount importance in the South African sheep industry (Olivier 1999). Against this background, two Merino lines were divergently selected over ~20 years to differ substantially in their ability to rear multiple offspring (Cloete *et al*. 2004). In a subsequent study on mature Merino ewes from these lines, a difference also was reported for susceptibility to breech strike, with the line selected for reproduction (High (H) line) being considerably more resistant than the line selected against reproduction (Low (L) line) (Scholtz *et al*. 2010b). It is also known that unmulesed hoggets in the H line were more plain-bodied than their contemporaries in the L line (Cloete *et al*. 2005). In this context, early studies in Australia indicated that breech conformation was associated with the susceptibility of Merino sheep to breech strike (Bull 1931, Seddon 1931, Seddon *et al*. 1931, Joint Blowfly Committee 1933, 1940, Beveridge 1935, Belschner 1937, MacKerras 1937, Seddon and Belschner 1937). Options for the control of breech strike were rather limited at that stage, and this led to the development of the Mules operation by Mr JWH Mules in 1931. Even at this stage, the Joint Blowfly Committee (1940) cautioned that '*The Mules operation must not be regarded as an alternative to the policy of breeding towards plain-breeched sheep*'. From South Africa it was reported that blowfly strike in the breech could be considerably reduced, if sheep were selected to eliminate susceptible crutches (De Vries and De Klerk 1943, 1944, Turpin 1947). It was furthermore recommended that '*the bare patch in the locality of the anus and vulva should be as large as possible*' (De Vries and De Klerk 1944). Belschner (1953) argued that it is very important, from a flystrike control and general hygiene perspective, that the anus, vulva and udder of ewes and the anus and pizzle of rams and wethers be surrounded by areas which are completely free of wool growth.

Despite these recommendations, genetic solutions to breech strike were not pursued further at that stage, most probably because of the exceptional effectiveness of surgical mulesing. However, mulesing impinges on animal welfare and is therefore internationally not acceptable as a breech strike control method anymore (People for the Ethical Treatment of Animals 2004, James 2006, National Woolgrower's Association 2009). Since mulesing is not a viable alternative any more, genetic solutions to breech strike are being revisited and selective breeding for resistance to breech strike is now considered to be the best long-term solution, for it is not only cumulative and permanent once a trait is fixed in the flock, but it is also painless (James 2006, Lee and Fisher 2007, Murray *et al*. 2007, Edwards *et al*. 2009, Greeff and Karlsson 2009, Smith *et al*. 2009a, b). Apart from wrinkle scores, indicator traits alleged to be associated with breech strike include breech cover score and crutch cover score. Dag score was also genetically related to breech strike in the study of Greeff and Karlsson (2009). These traits were thus studied in mature ewes from the H and L lines in an attempt to relate the proven line difference in breech strike prevalence (Scholtz *et al*. 2010b) to these subjective scores under South African conditions.

MATERIALS AND METHODS

Animals, location and recordings

Two lines of Merino sheep were divergently selected from the same base population from 1986 to 2009, using maternal ranking values for number of lambs reared per joining, as described by Cloete *et al*. (2004). Details of the origin of the lines and the procedures for the selection of replacements have been reported elsewhere (Cloete and Scholtz 1998, Cloete *et al*. 2004). Briefly, male and female progeny of ewes that reared more than 1 lamb per joining (i.e. reared twins at least once) were preferred as replacements in the H line. Replacements in the L line were preferably descended from ewes that reared fewer than one lamb per joining (i.e. barren, or loss of all lambs at least once).

The resource flock studied was maintained at the Elsenburg Research farm. The climate, pastures grown and management of the animals were adequately described by Cloete *et al*. (2004), while lambing and reproduction practices in the breeding flock were described by Cloete and Scholtz (1998). The climate at the experimental site is Mediterranean, with a winter lambing season (June-July) and pre-lamb shearing in May being practiced routinely. All animals were tail docked at the third palpable joint as lambs, while mature ewes were shorn in April/May and crutched in springtime (5 – 6 months' wool growth) to reduce the probability of strikes over the festive season (Scholtz *et al*. 2010b). The literature sources listed above may be consulted for additional information on these aspects.

Mature reproducing ewes (2 – 7+ years) and maiden ewes (~18 months old) were scored for dags; breech cover and crutch cover using the Visual Breech Scoring System (Australian Wool Innovation Limited 2007) of Australia. All scores were assessed on the maiden and mature reproducing ewes in November, a month after the weaning of the lambs of the reproducing ewes. Scores of 1 to 5 were allocated to each trait with a score of 1 depicting least expression of the trait and a score of 5 depicting most expression of that specific trait. In addition, quality of belly wool was evaluated for hairiness (present = 1; or absent = 0), shedding of wool (present = 1; or absent = 0) and wool quality (on a linear score from 1 to 5; where 1 = poor quality to 5 = good quality). Wool quality was defined as the regularity and definition of crimp, softness of handle and the absence of coarse fibres.

Statistical Analyses

Data pertaining to dag scores, breech cover scores, crutch cover scores and belly quality scores were subjected to least squares analysis to account for uneven subclasses (Harvey 1990). The fixed model used included the effects of selection line (H versus L line) and reproduction status (reared no lambs versus reared 1+ lamb). Ewe age (2 - 7+years) was also included as a fixed effect. Ewe age only affected means for dag score significantly ($P < 0.05$), but no specific age trend could be discerned. This effect was thus excluded from the results section. Number of lambs weaned during the 2009 lambing season was analysed according to the Chi-squared method described by Brown (1988).

Similar techniques were used for analyses on maiden ewes (~18 months old), but selection line was included as a single fixed effect in this case, making it a one-way analysis (Snedecor and Cochran 1967). Frequencies were analysed with Chi-square procedures, where needed (Van Ark 1990).

RESULTS

Mature ewes: Effects of selection line and reproduction status

Number of lambs weaned per ewe joined amounted to 0.922 in the H line and 0.565 in the L line (Chi-square = 6.90; degrees of freedom = 1; $P < 0.05$). The interaction between selection line and reproduction status was not significant for any score recorded on the mature ewes (Table 1).

Table 1. Least squares means (± s.e.) depicting the impact of selection line and previous reproduction on traits alleged to be associated with breech strike in mature reproducing ewes.

Selection line (SL)	**H line**		**L line**		**Effects$^{\#}$**		
Rearing status (RS)	**Reared 1+ lamb**	**Reared no lambs**	**Reared 1+ lamb**	**Reared no lambs**	**SL**	**RS**	**SL x RS**
Scores (1 - 5)							
Observations (n)	81	22	12	11			
Dag score	1.23 ± 0.04	1.05 ± 0.08	1.24 ± 0.10	1.25 ± 0.10	0.22	0.33	0.26
Breech cover	2.05 ± 0.13^{a}	2.75 ± 0.24^{b}	2.48 ± 0.32^{b}	3.38 ± 0.32^{c}	*	**	0.69
Crutch cover	1.32 ± 0.09^{a}	2.08 ± 0.18^{b}	1.97 ± 0.24^{b}	2.82 ± 0.24^{c}	**	**	0.84
Belly quality	1.67 ± 0.09^{a}	2.57 ± 0.17^{b}	2.23 ± 0.22^{b}	3.16 ± 0.22^{c}	**	**	0.94

^{a,b,c} Means followed by different superscripts in rows differ significantly ($P < 0.05$)

$^{\#}$ Actual P values are given for $P > 0.05$

* $P < 0.05$

** $P < 0.01$

Dag score was independent of selection line, as well as reproduction status ($P > 0.20$). Ewes in the H line rearing 1+ lamb had lower breech cover, crutch cover and belly wool quality scores than all the other groups ($P < 0.05$). H line ewes rearing no lambs and L line ewes rearing 1+ lamb were generally intermediate, with L line ewes rearing no lambs having the highest scores ($P < 0.05$). The absence of a significant interaction between selection line and reproduction status allows the independent assessment of the fixed effects. Expressed relative to H line performance, overall breech cover scores were 22% higher in L line ewes than in H line ewes (2.93 ± 0.23 versus 2.40 ± 0.14; $P < 0.05$). Corresponding selection line differences amounted to 41% for crutch cover score (2.39 ± 0.17 versus 1.70 ± 0.10; $P < 0.01$), and 27% for belly wool quality score (2.69 ± 0.16 versus 2.12 ± 0.10; $P < 0.01$). With the exception of dag score, subjective scores allocated to ewes rearing no lambs were higher than those of ewes rearing 1+ lamb ($P < 0.01$; Table 1). These differences amounted to 35% for breech cover score (3.06 ± 0.20 versus 2.27 ± 0.23), 49% for crutch cover score (2.45 ± 0.15 versus 1.64 ± 0.13), and 47% for belly quality score (2.86 ± 0.14 versus 1.95 ± 0.12).

Mature ewes: Quality of belly wool

The bellies of ewes that reared 1+ lamb were more likely to be hairy than those of ewes that failed to rear a lamb (43/93 = 0.462 versus 8/33 = 0.242; Chi-square = 4.02; degrees of freedom = 1; $P < 0.05$). A corresponding tendency for the shedding of belly wool was not significant (38/93 =

0.409 versus 8/33 = 0.242; Chi-square = 2.23; degrees of freedom = 1; $P > 0.10$). Analyses within selection lines were inconclusive, possibly owing to too few observations. It was nonetheless interesting to note that negligible absolute differences were found in the L line for hairiness (2/11 = 0.182 for ewes rearing no lambs versus 3/12 = 0.250 for ewes that reared 1+ lamb) and for the shedding of belly wool (3/11 = 0.273 for ewes rearing no lambs versus 3/12 = 0.250 for ewes that reared 1+ lamb). As the total observed frequency for these analyses were between 20 and 40 and at least one expected frequency was below three, the Chi-square test had a weak discriminatory power. Fisher's exact probability values were $P = 0.54$ for the hairiness of belly wool and $P = 0.72$ for the shedding of belly wool. The absolute differences in the H line were somewhat larger for hairiness (6/22 = 0.273 for ewes rearing no lambs versus 40/81 = 0.494 for ewes that reared 1+ lamb; Chi-square = 2.59; degrees of freedom = 1; $P < 0.25$) and the shedding of belly wool (5/22 = 0.227 for ewes rearing no lambs versus 35/81 = 0.432 for ewes that reared 1+ lamb; Chi-square = 2.25; degrees of freedom = 1; $P < 0.25$).

Maiden ewes: Effect of selection line

In maiden ewes, where scores were not complicated by reproduction, scores were higher ($P < 0.01$) in the L line, with the exception of belly quality score, where only a tendency to the same effect ($P = 0.07$) were found (Table 2). Expressed relative to mean H line performance, these differences amounted to 63% for dag score, 34% for breech cover score and 33% for crutch cover score.

Table 2. Least squares means (± s.e.) depicting the effect of selection line on traits alleged to be associated with breech strike in maiden ewes.

Scores (1 - 5)	**Selection line**		**Significance**[#]
	H line	**L line**	
Observations (n)	73	4	
Dag score	1.31 ± 0.06	2.13 ± 0.27	**
Breech cover	3.36 ± 0.08	4.50 ± 0.35	**
Crutch cover	2.64 ± 0.09	3.50 ± 0.38	*
Belly quality	2.97 ± 0.08	3.63 ± 0.35	0.07

[#] Actual P values are given for $P > 0.05$

* $P < 0.05$

** $P < 0.01$

DISCUSSION

Reproduction in mature ewes

Line differences in reproduction between the selection lines were not unexpected, as previous studies reported a similar trend in reproduction rates for the H and L lines (Cloete and Scholtz 1998, Cloete *et al*. 2004). The overall levels of reproduction were arguably lower in the lambing season considered when compared to previous references. The poorer reproduction during the year under study may be related to episodes of high rainfall during peak lambing. A total precipitation of 274.2mm was recorded for June-July 2009, which was nearly 50% higher than the long-term average of 185.2mm for these months. During the worst of these intense rainfall episodes from 21 June to 24 June, 30% of 70 viable recently-born lambs succumbed. This event alone accounted for 6% lamb mortality for the entire lambing season, expressed in relation to all those lambs born alive. Predation of lambs by caracal and domestic dogs was a secondary cause for a lower than expected reproduction, as 7.5% of those lambs that were tail-docked fell prey to these damage-causing animals prior to weaning.

Line differences in crutch and belly wool characteristics

In the absence of a significant interaction of selection line with reproduction status (Table 1), these effects are discussed separately. It is evident that mature H line ewes had lower scores (i.e. an increased bareness) for breech and crutch cover than L line contemporaries, irrespective of their reproduction status (Table 1). This result was supported by similar line differences in the maiden ewes, where the complication of reproduction was absent (Table 2). These results support an argument that the reduced susceptibility of H line ewes to breech strike compared to the L line (Scholtz *et al*. 2010b) may partially be attributed to an increased bare area in the breech and crutch regions. It could be argued that differences in udder shape and size could have contributed to the difference in crutch cover scores between reproducing H and L line ewes. However, this factor was not present in maiden ewes assessed, but a line significant difference of the same magnitude and in the same direction was observed. This adds robustness to the assessment that selection for reproduction results in lower crutch cover scores. Although no significant line difference was observed for dag score in mature ewes, maiden H line ewes also had lower dag score than their L line contemporaries. In this respect, Scobie *et al*. (1997) argued that it is the wool in the breech area that is causing the problem, for if this wool was not there in the first place; the dags and stains that attract blowflies would not accumulate. Rathie *et al*. (1994) promoted an ‘easy-care’ Merino – a sheep that requires neither mulesing nor crutching, only minimal husbandry for the control of blowfly strike on the body, where more valuable wool on the sheep is arguably grown. With the renewed interest in a genetic solution to breech strike, it is thought that resistance to breech strike can be achieved through selection on indicator traits such as wrinkles, bare area around the breech, dags, and urine stain (James 2006, Murray *et al*. 2007). Research reported that indicator traits such as bare breeches (Scobie *et al*. 2002, Hebart *et al*. 2006, James 2006, Scobie *et al*. 2008, Edwards *et al*. 2009, Greeff and Karlsson 2009) and a reduction of dags in the breech area (Karlsson *et al*. 2001, James 2006, Scobie *et al*. 2007, Greeff and Karlsson 2009) play a role in the reduction of breech strike in Merinos. Greeff and Karlsson (2009) accordingly reported genetic correlations of respectively 0.17 for breech cover score and 0.86 for dag score with the incidence of breech strike. Murray *et al*. (2007) contended that selection of Merino ewe lambs for low wrinkle-, dag- and urine stain scores and for breech bareness can be effective as mulesing in preventing breech blowfly strike. Traits such as breech wrinkle, urine stain, and wool characteristics (colour, fibre diameter variability, etc.) were also identified as indicator traits for resistance to breech strike in other studies (James 2006, AWI 2007, Murray *et al*. 2007, Karlsson *et al*. 2008, Smith and Filmer 2008, Scholtz *et al*. 2010a). In contrast, Smith *et al*. (2009a) found no evidence that lower breech cover scores were associated with a reduced incidence of breech strike. Based on earlier research of Scholtz *et al*. (2010b), our research supports an argument that breech cover score and dag score are related to breech strike. It also suggests that selection of Merino sheep for an increased reproduction rate is likely to lead to a desirable change in breech and crutch characteristics. In this respect, Belschner (1953) argued that the anus, vulva and udder of ewes and the anus and pizzle of rams and wethers should be surrounded by areas which are completely free of wool growth for the control of flystrike as well as for general hygiene. Scobie *et al*. (1997, 1999) proposed the breeding of an ethically improved sheep, wherein bareness of wool on the head, legs and belly is strived for.

The presence of line or breed differences are often used as an indication of genetic variation in a specific trait of interest. High heritability estimates, ranging from 0.45 to 0.48 were accordingly reported for crutch cover score in adult Merino ewes (Edwards *et al*. 2009, Smith *et al*. 2009b). Crutch cover score at hogget age was also highly heritable, at 0.42 to 0.54 (Edwards *et al*. 2009, Greeff and Karlsson 2009, Smith *et al*. 2009b). Somewhat lower heritability estimates of 0.38 at five months of age (Edwards *et al*. 2009) and of 0.33 at weaning (Scobie *et al*. 2007) were reported for lambs. The most appropriate age for selection for bareness score is as hoggets when there is no confounding effect of pregnancy or lactation and when the effects of birth type (single or multiple) have diminished (Edwards *et al*. 2009).

Significant genetic variation in breech strike of Merinos on the underlying scale were also reported by Greeff and Karlsson (2009) and Scholtz *et al*. (2010a). Seeing that breech cover, crutch cover and wrinkles are alleged to be associated with breech strike, results from this study are seen as important in elucidating underlying mechanisms associated with the incidence of breech strike in the population studied.

Belly quality scores in mature H line ewes were below scores for L line contemporaries, while a corresponding trend in the L line approached significance ($P < 0.07$). We could not find results in the literature that confirm of refute these findings. Results pertaining to the hairiness of belly wool and the shedding of belly wool were inconclusive, since differences between reproduction status classes within lines could not be demonstrated conclusively. The impact of reproduction on these traits within lines needs to be studied further.

Impact of reproduction on crutch and belly wool characteristics

Reproduction resulted in lower scores for breech and crutch cover in both the H and L lines, i.e. ewes rearing 1+ lamb(s) became barer than those that failed to rear a lamb (Table 1). These results are consistent with findings by Edwards *et al*. (2009) that subsequently dry ewes received a higher score (i.e. they became woollier) compared to their previous scores when they lactated.

Lactating ewes accordingly became barer compared to their previous scores. Lactation status accounted for ~ 10% of the change in bareness scores in the ewes in the latter study. However, it must be stated that cover score had a fairly low repeatability of 0.42. Edwards *et al*. (2009) ascribed this to either inaccuracies in subjective score allocation and/or to changes induced by the environment or age of the animals.

The bellies of ewes that reared 1+ lamb(s) were more likely to be hairy than those of ewes that failed to rear a lamb, but no conclusive difference was found for the incidence of belly wool being shed. Tierney (1978) crossed the Wiltshire Horn (WH) breed with Merinos to determine if the fleece-shedding characteristics of the WH could be transferred to Merinos. The intention of the study was to produce a predominantly Merino sheep that would be relatively resistant to blowfly strike. It is also argued that belly wool is of lower quality than fleece wool (Scobie *et al*. 1997). Moreover, belly wool is more difficult to harvest, predisposing ewes to cut teats and udders with a concomitant reduction in lamb survival.

CONCLUSIONS

The present study suggests that Merino sheep selected for reproduction rate display desirable breech and crutch characteristics compared to contemporaries selected against reproduction. This generalisation held true for mature reproducing ewes as well as for two-tooth hoggets. Dag scores were accordingly improved in hoggets. These results contribute to growing evidence of a favourable genetic association between a high reproduction rate and a reduced susceptibility to breech strike in wool sheep, as suggested by Scholtz *et al*. (2010a, b). Because of its economic importance, an improved reproduction rate is seen as an important selection goal for Merino sheep in South Africa (Olivier 1999). An improved resistance to breech strike, resulting in the Mules operation becoming redundant, would be an important additional benefit of selection for reproduction. Such an approach would be desirable from ethical, animal welfare and sustainability perspectives.

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CHAPTER 8

GENETIC (CO)VARIANCES FOR BREECH STRIKE INDICATOR TRAITS AND YEARLING WOOL AND BODY WEIGHT TRAITS IN MERINO LINES DIVERGENTLY SELECTED FOR REPRODUCTION

GENETIC (CO)VARIANCES FOR BREECH STRIKE INDICATOR TRAITS AND YEARLING WOOL AND BODY WEIGHT TRAITS IN MERINO LINES DIVERGENTLY SELECTED FOR REPRODUCTION

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ABSTRACT

Genetic (co)variances for breech traits were estimated for 741 to 963 yearling Merino sheep that were born in a divergent selection experiment for reproduction rate, with a line selected for reproduction (High or H line) and a line selected against reproduction (Low or L line). Crosses between these lines were also present in the period under study. Breech traits that were considered were autumn dag score, spring dag score, breech wrinkle score, as well as the width and depth of bare area around the perineum. All traits exhibited genetic variation, heritability estimates ranging from 0.21 for autumn dag score as well as depth of bare area to 0.53 for breech wrinkle score. Dag scores in autumn and spring were highly correlated on the genetic level (0.67). However, this correlation differed from unity. Breech wrinkle scores were positively related to dag scores on the genetic level, while autumn dag scores were negatively related to the breech bare areas. The only other genetic correlation of significance was a positive genetic correlation between depth and width of the bare area (0.72). Genetic correlations of yearling live weight with the recorded breech traits were all in the desired direction, and only the genetic correlation with breech wrinkle score failed to reach a level of double the corresponding standard error. The only other genetic correlation of importance was between clean fleece weight and breech wrinkle score, suggesting that sheep with heavier fleeces would have more wrinkly breeches. Averaged breeding values for dag scores and breech wrinkle score in the H and L lines were roughly symmetric about zero, indicating substantially less dags and plainer breeches in the H line. Breeding values for breech bare area responded in much the same way, indicating larger bare areas in the H line. However, the absolute values for the lines were different in this case, the L line being closer to zero compared to the H line. The crossbred lines were intermediate, as would have been expected. On average, 3.3% of yearlings evaluated during 2007 and 2008 contracted breech strike. Animals with pooled L line genetics (the L line as well as F1 crosses backcrossed onto the L line) were more likely to contract breech strike than pooled H line animals (the H line as well as F1 crosses backcrossed onto the H line) (1.5% versus 10.5%). It was concluded that breech traits were heritable, and that genetic progress was likely to follow directed selection. Selection for an increased reproduction also seemed to result in favourable breech traits, as well as a reduced susceptibility to breech strike in animals with a H line genetic background.

Keywords: resistance to flystrike, genetic parameters, breeding values

INTRODUCTION

Numerous scientific studies report on the genetic variation that exists both between and within sheep breeds for resistance to body strike (Raadsma 1987, Raadsma and Rogan 1987, Mortimer *et al*. 1998). More recently, with the cessation of mulesing as a method to control breech strike, studies have been increasingly directed towards genetic alternatives for the prevention of breech strike as well (Scobie *et al*. 2002, Murray *et al*. 2007, Edwards *et al*. 2009, Greeff and Karlsson 2009, Smith *et al*. 2009a, b, Scholtz *et al*. 2010a, b). A number of traits, including wrinkle scores, breech cover/breech bareness scores, dag scores, urine stain and wool colour scores were identified as potential indicator traits for the prevention of breech strike. A limited number of genetic parameters for these indicator traits are available in the literature; indicating that they do exhibit additive genetic variation (Greeff and Karlsson 2005, James 2006, Murray *et al*. 2007, Karlsson *et al*. 2008, Smith *et al*. 2009a). Based on these preliminary estimates, genetic change in these traits seems to be feasible. To set up breeding programs, however, information on the relationship between traits associated with breech strike resistance, and other traits of economic importance, namely live weight, fleece characteristics as well as reproduction are essential. At this stage there is a paucity of scientific literature on this topic.

The objective of this study was to determine genetic parameters for some of the indicator traits (dag score, breech wrinkle score and bare area) for breech strike against this background, and to examine genetic and phenotypic correlations with live weight, clean fleece weight and fibre diameter in Merino lines that were divergently selected for their ability to rear multiple offspring.

MATERIALS AND METHODS

Animals and selection procedures

Two lines of Merino sheep were divergently selected from the same base population from 1986 to 2009, using maternal ranking values for number of lambs reared per joining initially (Cloete *et al*. 2004). These maternal ranking values were augmented with breeding values from single trait repeatability model analyses from the progeny group of 2002 and subsequently, as described by Cloete *et al*. (2009). Details of the procedure for the selection of replacements have been reported elsewhere (Cloete and Scholtz 1998, Cloete *et al*. 2004, 2009, Scholtz *et al*. 2010b, Chapter 5). Briefly, male and female progeny of ewes that reared more than one lamb per joining (i.e. reared twins at least once) were preferred as replacements in the High (H) line. Replacements in the Low (L) line were preferably descended from ewes that reared less than one lamb per joining (i.e. barren, or loss of all lambs at least once). Depending on average reproduction rates in the lines, and on replacement needs, progeny of ewes that reared one lamb per joining were occasionally selected in either line. Selection decisions were mostly based on ≥3 maternal joinings, especially in the case of rams. Once selected, ewes normally remained in the breeding flock for at least five joinings, except when exiting earlier because of death and mouth or udder malfunction. The literature sources listed above may be consulted for additional information on these aspects.

Since 2003, part of the breeding flock was subjected to reciprocal crossbreeding between the two lines, with the intention of forming a genetic resource population for possible future genomic projects (Naidoo *et al*. 2005). Crossbred progeny were available from the 2003 year of birth onwards, whereas backcrosses became available from 2005.

Location and recordings

For the duration of the study, the lines were maintained on the Elsenburg Research farm (33º 51' S, 18º 50' E) near Stellenbosch in the south-western region of the Western Cape province of South Africa. The climate at the experimental site is Mediterranean, with 78% of the average rainfall of 606 mm being recorded in the months from April to September. Ewes from both lines were predominantly maintained as a single flock. The only times they were separated were during joining in single sire groups and when recently lambed ewes were randomly allocated to smaller mobs of 20 – 30 ewes with their lambs, after being moved from the lambing paddocks. Joining took place in summer (January - February), for lambing during the winter (June - July) of the same year. Irrigated kikuyu (*Pennisetium clandestinum*) paddocks were utilised during joining and lambing (Cloete and Scholtz 1998). Dryland lucerne (*Medicago sativa*) and medic (*M. truncatula*) pastures were predominantly used. Small grain fodder crops (mostly oats) were occasionally grazed in winter, while small grain crop residues and oat standing hay were seasonally available during spring and early summer.

The animals used in this study were the 2004 - 2008 lamb drops. All lambs were tail docked at the third palpable joint at roughly three weeks of age and shorn in September - October as weaner lambs to remove the halo hairs of the lamb fleece. The animals were scored for dags in April or May (autumn dag score) as yearlings (10 - 11 months old) and shorn afterwards. Midrib wool samples were taken from each animal at shearing, or just prior to shearing. These samples were sent to the Wool Testing Bureau in Port Elizabeth to be analysed for fibre diameter and clean yield. Information on the latter trait was used to derive clean fleece weight from the greasy fleece weight recorded at shearing. After being shorn all the animals were weighed and two measurements of the bare area around the perineum were made, namely the width of the bare area (WBA) as well as the depth of the bare areas (DBA). A caliper was used to measure the width of the bare area (area without wool) as the widest diameter horizontally across the perineum and the depth of the bare area as the diameter of the bare area underneath the tail, starting where the tail joins the body, and ending where the wool growth commences (James 2006). Breech wrinkle scores were also determined at this stage by making use of a photographic system similar to the Visual Breech Scoring System (Australian Wool Innovation Limited 2007). However, the breech wrinkle scorecard used had six categories (e.g. Score of 1 = least expression of the trait; Score 6 = most expression of that specific trait), in contrast to the five categories used in the former system.

The occurrence of flystrike was recorded in the experimental animals in the period from shearing as weaners and yearlings in the lambing years of 2007 and 2008. The scoring system used by Scholtz *et al*. (2010b) was applied.

Dags were also scored on all the animals as hoggets prior to being crutched in September (spring dag score) when they were approximately 15 months old. Scoring was done by making use of the scoring system as described in chapter 4 which is in accordance with the Visual Breech Scoring System (Australian Wool Innovation Limited 2007). During the allocation of these scores, provision was made for half scores in situations where the dag scores for specific animals were situated between two of the five fixed categories for dags.

Statistical analyses

Environmental factors that were considered for all the breech traits included year of birth (2004 to 2008), gender (male or female), age of dam (2 to 7+ years) and birth type (single or pooled multiples). The identity of the sire and dam of lambs were known individually. This information enabled linkage back to the line they were born in. The ASREML program (Gilmour *et al*. 2006) was used for the analysis of the fixed effects, and also to estimate variance components in single-trait analyses. The first analysis involved fitting various combinations of fixed effects and two-factor interactions to obtain an operational model. The random term of animal was then added to the operational model, resulting in the following model for analyses (in matrix notation):

$$y = Xb + Z_1a + e \qquad (1)$$

In these analyses, y was a vector of observations for breech traits, and b a vector of fixed effects; a a vector of direct genetic variances, while e was the vector of residuals.
It was assumed that:

$$V(a) = A\sigma^2_a;\ V(e) = I\sigma^2_e,$$

with A the numerator relationship matrix; I an identity matrixes; σ^2_a, and σ^2_e the direct additive genetic variance, and environmental (residual) variance respectively. These analyses yielded estimates of genetic and environmental variances. Ratios for direct additive genetic variances of the respective traits were computed from these estimates. These variances were expressed relative to the total phenotypic variance. Subsequently, a five-trait animal model was fitted, allowing the calculation of all relevant correlations between traits, together with the appropriate standard errors. Since heritability estimates did not differ appreciably between single trait and the six-trait analysis, (co)variance components and ratios from the latter were tabulated in Table 3.

Direct breeding values for breech traits were obtained as animal solutions from the six-trait analysis, and compared statistically for selection lines using one-way-analysis of variance procedures. These means were inspected for differences between lines, using the appropriate standard errors. Standard Chi-square procedures were used to compare selection lines for the frequency of breech strike, where appropriate (Van Ark 1990).

RESULTS

Descriptive statistics

The number of records ranged from 741 for spring dag score to 963 for autumn dag score (Table 1). The distribution of all data was within the accepted boundaries for normality, but coefficients of variation (CV) for the dag scores exceeded 50%. Breech wrinkle score also had a high CV of 39%, but the CV's of the depth of the bare area and the width of the bare area were lower at respectively 16 and 21%.

Table 1. Descriptive statistics for the breech traits autumn dag score (ADS), spring dag score (SDS), breech wrinkle score (BWS), depth of bare area (DBA) and width of bare area (WBA).

Statistics	**Trait**				
	ADS	**SDS**	**BWS**	**DBA**	**WBA**
Number of records	963	741	951	948	948
Mean	1.75	1.93	2.60	70.0	46.1
Standard deviation	0.95	0.99	1.02	11.1	9.8
Range	1 – 5	1 – 5	1 – 6	26 – 100	19 – 79
Skewness	1.55	1.55	0.36	-0.03	-0.21
Kurtosis	1.97	1.91	-0.28	0.07	-0.33

The effect of main effects on indicator traits

The only significant ($P < 0.05$) interactions between main effects were between birth year and gender for all traits. Gender interacted with birth year for autumn dag score and breech wrinkle score which are provided as examples (Fig. 1a, b). When trends for male and female animals were compared, it was clear that no consistent trend could be discerned.

Overall, significant year effects were found for all traits; except for breech wrinkle score (Table 2). Ewes were generally more daggy than rams in autumn, with no significant gender effect in spring. Breech wrinkle score was also independent of gender, while ram hoggets had generally deeper (DBA) bare areas than ewes. In contrast, ewes had wider (WBA) bare areas than rams.

Progeny of older ewes at 5 - 6 years of age had generally higher breech wrinkle scores than progeny of 2- and 3-year-old ewes (Table 2). The average depth of bare area was higher in progeny of ewes aged 5 and 6 years when compared to the progeny of 7+-year-old ewes. Multiple-born hoggets were less wrinkly in the breech than singles, while they had slightly shallower (WBA) bare areas.

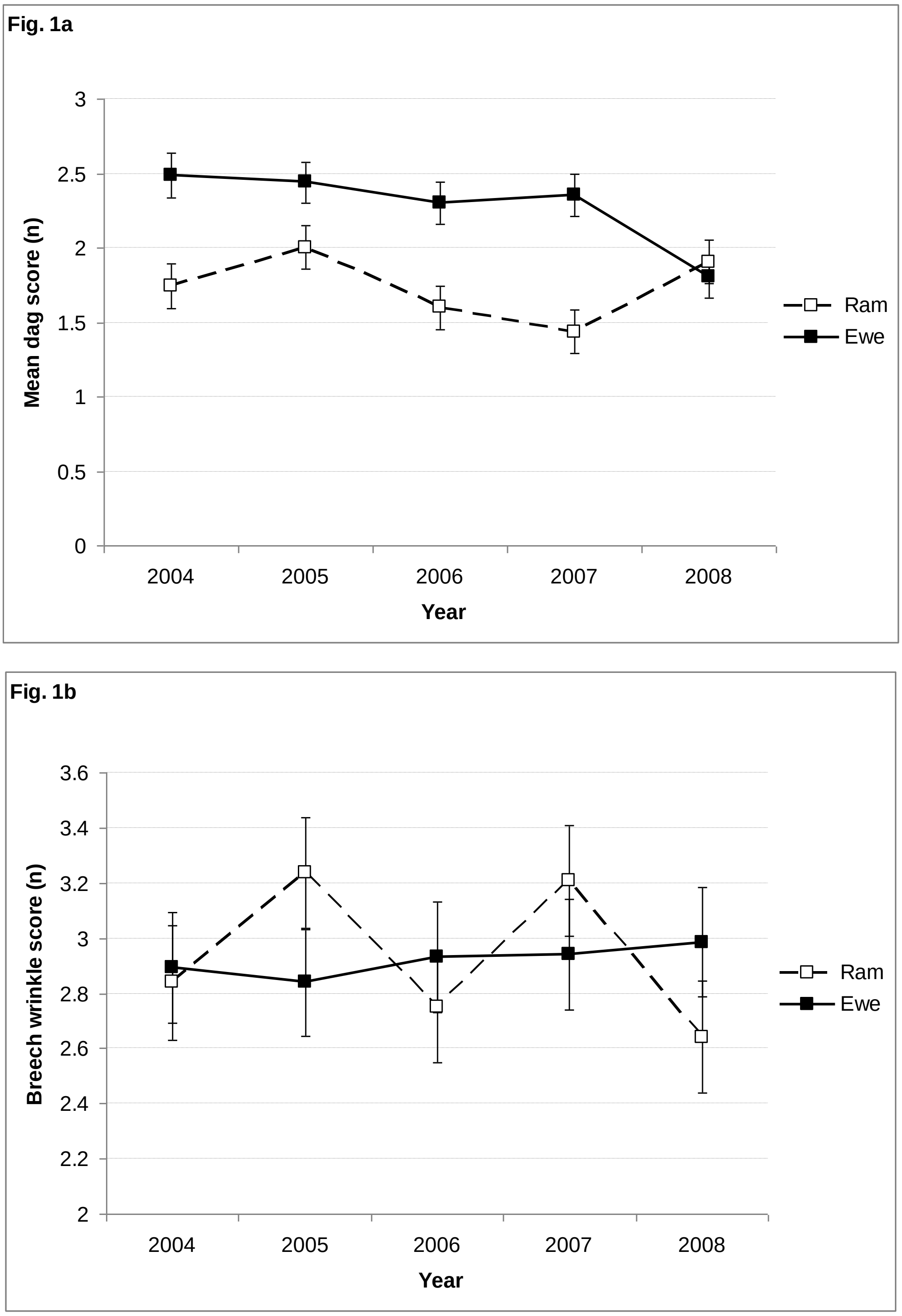

Fig. 1. Least squares means depicting the interaction of gender with birth year for autumn dag score (Fig. 1a) and breech wrinkle score (Fig. 1b) . Vertical lines about the means represent standard errors.

Table 2. Least squares means (± s.e.) depicting the effects of birth year, gender, dam age and birth type on autumn dag score (ADS), spring dag score (SDS), breech wrinkle score (BWS), depth of bare area (DBA) and width of bare area (WBA) in the breech.

Effect and level	Trait				
	ADS	SDS	BWS	DBA	WBA
Birth year	**	**	0.07	**	**
2004	2.11 ± 0.13	2.58 ± 0.18	2.87 ± 0.19	69.6 ± 1.6	39.2 ± 1.1
2005	2.22 ± 0.13	2.58 ± 0.18	3.04 ± 0.18	71.1 ± 1.5	52.3 ± 1.1
2006	1.95 ± 0.13	2.34 ± 0.18	2.84 ± 0.19	70.2 ± 1.6	48.7 ± 1.1
2007	1.89 ± 0.13	2.15 ± 0.19	3.07 ± 0.19	64.9 ± 1.6	41.9 ± 1.1
2008	1.85 ± 0.13	1.90 ± 0.19	2.81 ± 0.19	64.8 ± 1.6	37.8 ± 1.1
Gender	**	ns	ns	**	**
Male	1.74 ± 0.12	2.23 ± 0.17	2.93 ± 0.18	71.1 ± 1.4	41.4 ± 1.0
Female	2.28 ± 0.12	2.39 ± 0.17	2.92 ± 0.18	65.1 ± 1.4	46.6 ± 1.0
Age of dam	0.16	Ns	**	*	0.15
2 years	1.88 ± 0.13	2.23 ± 0.17	2.64 ± 0.19	67.0 ± 1.6	43.1 ± 1.1
3 years	1.91 ± 0.13	2.24 ± 0.17	2.78 ± 0.19	67.7 ± 1.6	43.9 ± 1.1
4 years	2.01 ± 0.13	2.31 ± 0.17	2.88 ± 0.19	68.8 ± 1.5	43.8 ± 1.1
5 years	1.96 ± 0.13	2.30 ± 0.17	3.11 ± 0.18	69.5 ± 1.5	44.9 ± 1.1
6 years	2.11 ± 0.14	2.34 ± 0.17	3.20 ± 0.19	69.9 ± 1.6	44.8 ± 1.1
7+ years	2.14 ± 0.15	2.45 ± 0.17	2.94 ± 0.20	65.8 ± 1.7	43.4 ± 1.2
Birth type	0.14	ns	**	*	ns
Single	2.05 ± 0.12	2.34 ± 0.17	3.14 ± 0.18	69.4 ± 1.4	44.7 ± 1.0
Multiple	1.96 ± 0.12	2.29 ± 0.17	2.71 ± 0.18	66.8 ± 1.4	43.3 ± 1.0

* $P < 0.05$; ** $P < 0.01$; ns – Not significant ($P > 0.20$)

Heritability and genetic correlations

All traits were heritable, estimates of h^2 ranging from 0.21 for autumn dag score and depth of breech bare area to 0.53 for breech wrinkle score (Table 3). Dag scores in autumn and spring were highly correlated on the genetic level. However, this correlation differed from unity, suggesting that some of the genes affecting dag scores in the respective seasons may be different. Breech wrinkle scores were positively related to dag scores on the genetic level, while autumn dag scores were negatively related to the breech bare areas. Daggy sheep would thus be likely to be wrinkly, with comparatively smaller bare areas around the perineum. The only other genetic correlation of significance was a positive genetic correlation between depth and width of bare area. Phenotypic correlations resembled genetic correlations in direction, but were generally smaller in magnitude.

Table 3. (Co)variance components and ratios (± s.e.) for autumn dag score (ADS), spring dag score (SDS), breech wrinkle score (BWS), depth of bare area (DBA) and width of bare area (WBA) in the breech.

Component and trait	**ADS**	**SDS**	**BWS**	**DBA**	**WBA**
Heritability (h^2) in bold on the diagonal with genetic correlations above the diagonal					
ADS	**0.21 ± 0.06**	0.67 ± 0.14	0.50 ± 0.15	-0.61 ± 0.19	-0.45 ± 0.20
SDS		**0.45 ± 0.09**	0.46 ± 0.14	-0.12 ± 0.20	-0.01 ± 0.19
BWS			**0.53 ± 0.08**	-0.23 ± 0.19	-0.17 ± 0.17
DBA				**0.21 ± 0.06**	0.72 ± 0.14
WBA					**0.28 ± 0.08**
Phenotypic variance (σ^2_P) in bold on the diagonal with phenotypic correlations above the diagonal					
ADS	**0.725**	0.28 ± 0.04	0.28 ± 0.04	-0.12 ± 0.04	-0.15 ± 0.04
SDS		**0.918**	0.14 ± 0.04	-0.06 ± 0.04	-0.06 ± 0.04
BWS			**0.968**	-0.04 ± 0.04	-0.09 ± 0.04
DBA				**103.2**	0.48 ± 0.03
WBA					**44.53**
Environmental variance (σ^2_E) on the diagonal with environmental correlations above the diagonal					
ADS	**0.569**	0.12 ± 0.07	0.18 ± 0.07	0.01 ± 0.05	-0.05 ± 0.06
SDS		**0.505**	-0.17 ± 0.11	-0.04 ± 0.04	-0.09 ± 0.08
BWS			**0.452**	0.06 ± 0.07	-0.03 ± 0.08
DBA				**82.01**	0.41 ± 0.05
WBA					**32.10**

Correlation between breech traits and production traits

Genetic correlations of hogget live weight with the recorded breech traits were all in the desired direction, and only the genetic correlation with breech wrinkle score failed to reach a level of double the corresponding standard error (Table 4). Heavier animals would be less daggy, with larger bare areas and a suggestion of a lower breech wrinkle score. Genetic correlations of clean fleece weight with dag scores were negligible. Heavier cutting sheep would have higher breech wrinkle scores. The genetic correlations of clean fleece weight with breech bare areas were in the desired direction, but failed to reach significance. Genetic correlations with fibre diameter were mostly inconclusive, because it failed to reach a level of double the corresponding standard error. However, the absolute direction of these correlations was unfavourable for dag and breech wrinkle scores, suggesting that finer sheep would also have more dags and more wrinkly breeches. The same applied to breech bare areas, as animals with broader fibers would generally have larger bare areas on their breeches.

It is noted that the correlations between body weight and depth and width of bare were very high (respectively 0.86 and 0.70). It is accepted that part of this correlation is due to the size of the animal (i.e. larger animals have larger bare areas). Liveweight should possibly be considered as a covariate in future analyses on the depth and width of the bare area. More information is therefore needed before we can conclude that larger sheep are less prone to strike because they have larger bare areas.

Table 4. Genetic, phenotypic and environmental correlations of live weight, clean fleece weight and fibre diameter with autumn dag score (ADS), spring dag score (SDS), breech wrinkle score (BWS), depth of bare area (DBA) and width of bare area (WBA) in the breech.

Trait and type of correlation	Trait				
	ADS	**SDS**	**BWS**	**DBA**	**WBA**
Live weight					
Genetic	-0.69 ± 0.14	-0.55 ± 0.15	-0.18 ± 0.14	0.86 ± 0.07	0.70 ± 0.12
Phenotypic	-0.13 ± 0.04	-0.09 ± 0.04	-0.04 ± 0.04	0.54 ± 0.03	0.40 ± 0.03
Environmental	0.18 ± 0.07	0.34 ± 0.11	0.14 ± 0.10	0.37 ± 0.06	0.21 ± 0.07
Clean fleece weight					
Genetic	-0.01 ± 0.18	-0.03 ± 0.16	0.47 ± 0.12	0.28 ± 0.17	0.31 ± 0.16
Phenotypic	0.12 ± 0.04	0.05 ± 0.05	0.33 ± 0.04	0.27 ± 0.04	0.22 ± 0.04
Environmental	0.21 ± 0.07	0.13 ± 0.11	0.18 ± 0.10	0.28 ± 0.07	0.17 ± 0.08
Fibre diameter					
Genetic	-0.24 ± 0.14	-0.14 ± 0.14	-0.21 ± 0.12	0.10 ± 0.16	0.21 ± 0.14
Phenotypic	-0.05 ± 0.04	-0.04 ± 0.05	-0.11 ± 0.04	0.15 ± 0.04	0.19 ± 0.04
Environmental	0.13 ± 0.10	0.12 ± 0.13	0.08 ± 0.13	0.23 ± 0.09	0.22 ± 0.10

Breeding values for breech traits in the selection lines

Line specific averaged breeding values for the lines present in all years are presented in Table 5. Averaged breeding values for dag scores and breech wrinkle score in the H and L lines were roughly symmetric about zero, indicating substantially less dags and plainer breeches in the H line. Breeding values for the length and width of the breech bare area responded in much the same way, indicating larger bare areas in the H line. However, the absolute values for the lines were different ($P < 0.05$) in this case, the L line being closer to zero compared to the H line. The crossbred lines were generally intermediate, with averaged breeding values about zero for dag scores and for breech wrinkle score. However, H x L animals had positive averaged breeding values for the length and width of the bare area, while corresponding values in the L x H line were negative.

Frequency of breech strike in the respective selection lines

Of the 456 animals born from the 2007 lambing season and present at the recording of the autumn dag scores 15 (a frequency of 0.033) suffered from flystrike. All strikes were in the breech area, except for a single L line young ram that contracted both breech strike and poll strike. Line specific frequencies of breech strike were 3/266 = 0.011 in the H line, 2/23 = 0.087 in the L line, 3/42 = 0.071 in the reciprocal crosses between the H and L lines (cross animals), 5/43 = 0.116 in cross animals backcrossed onto the L line (i.e. 75% L line genetics) and 2/61 = 0.033 in cross animals backcrossed onto the H line (i.e. 75% H line genetics). The analysis of these frequencies by Chi-square procedures resulted in an analysis with a weak discriminatory power because of small cell sizes, and the pooling of data had to be considered. Groups were constructed to include H line animals pooled with backcrosses with a 75% H line genetic background (pooled H line group), as well as L line animals pooled with those animals with a 75% L line genetic background (pooled L line group). In a 2 x 2 contingency table involving these frequencies, the pooled H line group was less likely to contract breech strike than the pooled L line group (5/322 = 0.015 versus 7/66 = 0.106; Chi-square = 12.37, degrees of freedom 1; $P < 0.01$).

Table 5. Means (± s.e.) for predicted breeding values of autumn dag score (ADS), spring dag score (SDS), breech wrinkle score (BWS), depth of bare area (DBA) and width of bare area (WBA) in the breech in those selection lines that were present in all years from 2004 to 2008.

Selection line	**Trait**				
	ADS	**SDS**	**BWS**	**DBA**	**WBA**
H Line	-0.46 ± 0.01	-0.43 ± 0.02	-0.51 ± 0.02	4.84 ± 0.09	3.36 ± 0.08
L Line	0.41 ± 0.03	0.43 ± 0.05	0.43 ± 0.06	-3.74 ± 0.27	-1.85 ± 0.23
L x H line	0.16 ± 0.03	0.09 ± 0.04	-0.05 ± 0.05	-1.31 ± 0.23	-0.41 ± 0.19
H x L line	-0.09 ± 0.04	0.04 ± 0.06	0.08 ± 0.07	1.17 ± 0.31	0.74 ± 0.26

DISCUSSION

Descriptive statistics

The difference in the numbers available between the spring and autumn dag scores are mainly caused by dag scores not being recorded in spring during 2006. All data were distributed normally, but dag scores had CV's exceeding 50%. Comparable CV's reported by Greeff and Karlsson (2009) for dag scores ranged from 24 to 30%, but at relatively higher average dag scores of 2.4 to 2.6. The CV of 39% for breech wrinkle score was also higher than a previous estimate of 24% in the study of Scholtz *et al*. (2010a), but lower than CV's of >50% for breech wrinkle score in the study of Greeff and Karlsson (2009). The CV's of the depth of the bare area (DBA) and the width of the bare area (WBA) were lower at respectively 16 and 21%. Corresponding CV's measured at weaning in South Australian Merinos ranged from 17 to 27% (James 2006).

The effect of main effects on indicator traits

Significant year effects are a common feature of genetic analyses on sheep, and were also reported by Greeff and Karlsson (2009). Years are considered to represent a unique set of environmental and managerial conditions, unlikely to be repeated in subsequent years. Year is thus included in statistical models for the determination of genetic variances for the variation it controls. The gender by year interaction was significant for all breech traits. Such interactions are commonly found in the scientific literature (Cloete *et al*. 2007), as ram and ewe replacements are generally separated on gender close to weaning, and subsequently managed in separate flocks. The interactions stem from an inability to ensure equal treatment for such flocks consistently over years. In contrast to the present study, Greeff and Karlsson (2009) reported that ram hoggets had more dags than ewes. James (2006) reported that ewe weaners had a longer diameter of bare skin across the anus and across the vulva than their ram contemporaries, a finding which was consistent with the results from the present study. Smith *et al*. (2009a) reported that multiple lambs had lower breech wrinkle scores than singles, a finding which accorded with the present study.

Heritability and genetic correlations

Dag scores were heritable; estimates ranging from 0.21 for autumn dag score to 0.45 for spring dag score on the same animals (Table 3). Published heritability estimates for dag score vary widely with environment and age (Greeff and Karlsson 1998, 1999, Woolaston and Ward 1999). Bisset *et al*. (1992) reported a heritability estimate of 0.24 for dag score, while Meyer *et al*. (1983) reported an average heritability of 0.31 for dag score. These values were somewhat lower than the values reported by Watson *et al*. (1986 – 0.54) and Baker *et al*. (1991 – 0.41). Shaw *et al*. (1999) and Scobie *et al*. (2007) estimated heritability for dag score in other breeds at respectively 0.40 and 0.37. More recently Greeff and Karlsson (2009) reported a heritability estimate of 0.55 for dag score on Merino sheep in a Mediterranean environment. The estimates from the present study are consistent with the range of values cited above.

The heritability estimate for breech wrinkle score in this study (0.53; Table 3) was higher than a corresponding estimate of Lewer *et al*. (1995) of 0.19 but consistent with the majority of other estimates from the literature (summarized by James 2006). More recently Scholtz *et al*. (2010a, Chapter 6) reported heritability estimates for breech wrinkle score that ranged from 0.28 for hoggets subjected to mulesing to 0.45 for unmulesed hoggets. Moderate to high heritability estimates; ranging from 0.36 to 0.45, were also reported (McGuirk as cited by Raadsma and Rogan 1987, Greeff and Karlsson 2009, Smith *et al*. 2009a), indicating that substantial gains could be made in this trait by purposeful selection. With the high h^2 of wrinkle score, genetic change towards plainer–bodied animals should be easy to achieve (Turner 1977).

Heritability of depth (DBA) and width (WBA) of bare areas in this study was estimated at 0.21 and 0.28 respectively (Table 3). Scientific literature reported a heritability estimate of 0.23 for bare area in Merinos at marking time, where the bare area was calculated from height and width measurements and adjusted using liveweight (see review article by James 2006). Heritability estimates of 0.38, 0.53 and 0.45 were reported for subjectively scored bare breeches of Merinos at lamb; hogget and adult ages (Edwards *et al*. 2009).

Dag scores in autumn and spring were highly correlated on the genetic level (Table 3). However, this correlation differed from unity, suggesting that some of the genes affecting dag scores in the respective seasons may be different. The difference in heritability estimates between the autumn and spring dag scores can probably be ascribed to the difference in availability and quality of grazing as well as differences in the parasite burden on the pastures. Mediterranean environments are characterised by large seasonal fluctuations in rainfall and temperature and this affects the parasite population on the pasture markedly at different times of the year (Greeff *et al*. 1995). This is also the case in the Western Cape with its cold wet winters (June – August) and long dry summers (December – February) where the animals are not normally challenged during the warm dry summer months because very few parasitic larvae are present on the pasture. Quality and quantity of grazing is also relatively poor during the hot summer months. Bundy and Golden (1987) and Roberts and Adams (1990) reported that nutritional stress suppresses immunity. The low heritability of the autumn dag score might have stemmed from the effect the nutritional stress had on the expression of resistance. The higher heritability estimate for the spring dag score can probably also be ascribed to the better quality and quantity grazing during the winter months. Watts *et al*. (1978) found the occurrence of diarrhoea in ewes grazing long pastures to be at least double that of ewes grazing short pasture. It is notable that the overall mean of spring dag score was approximately 10% higher than that of autumn dag score. Horton and Champion (2001) reported that certain grazing situations may increase the risk of scouring. Khusro *et al*. (2004) reported heritability estimates of 0.21 and 0.38 for faecal worm egg count in Merinos at yearling and hogget ages respectively, indicating that heritability estimates might also differ with the age of the animal.

Sheep with higher breech wrinkle scores were genetically also more likely to have higher dag scores (Table 3). Genetic correlations for dags with breech wrinkle scores from our study are higher but in the same direction as a corresponding correlation of 0.07 reported at weaning age for Merinos by Greeff and Karlsson (2009). Smith *et al*. (2009a) reported genetic correlations of 0.02 and 0.09 for breech wrinkle score with breech cover score and crutch cover score respectively. Autumn dag score was negatively related to the diameters of the breech bare areas on the genetic level; with a correlation of -0.61 with depth of bare area and -0.45 with width of bare area. Scobie *et al*. (2007, 2008) reported genetic correlations ranging from -0.30 to -0.72 between dag scores and breech bare areas for composite breeds using a subjective scoring method. In accordance with the literature findings cited above, results from this study indicate that daggy sheep would thus be likely to have wrinkly breeches, with comparatively smaller bare areas around the perineum.

The only other genetic correlation of significance was a positive genetic correlation between the depth of bare area and the width of the bare area. No literature sources could be found to relate these results to. This finding could be an important finding if measurement of bare area can be carried out by recording either depth or width (depth might be easier) without requiring two values to be recorded. Phenotypic correlations resembled genetic correlations in direction, but were generally smaller in magnitude. Greeff and Karlsson (2009) cautioned that, although all the visually scored indicator traits from their study were genetically correlated with breech strike, dags followed by breech cover were the most important indicator trait of breech strike in the resource population they studied in a Mediterranean environment. They contended that environmental factors will be the key determining factor and that more information is needed to be able to estimate robust genetic and phenotypic parameters for the design of an efficient breeding program.

Correlation between breech traits and production traits

Genetic correlations of yearling production and product traits with the recorded breech traits were in the desired direction in the case of live weight (Table 4), and mostly negligible and smaller than a level of double the corresponding standard error in the case of fleece weight and fibre diameter. Selection lines at Trangie Agricultural Research station were selected from 1951 to 1971 for more wrinkles (Folds Plus) and less wrinkles (Folds Minus). Richards *et al*. (2009) reported little influence on body weight in the reduced wrinkle (+3%) or increased wrinkle flocks (+1%). This is in contrast with previous results from the resource flock used in the present study, where genetic correlations ranging from -0.24 to -0.27 suggested that heavier sheep would generally be plainer than lighter individuals (Cloete *et al*. 1998, Cloete 2002, Cloete *et al*. 2005). Results from this study indicate that heavier animals would also be less daggy, with larger bare areas and a suggestion of a lower breech wrinkle score. Although the results cannot be compared directly, Smith *et al*. (2009b) reported negative correlations between body weight and crutch cover scores in hoggets, namely -0.32 on the phenotypic level and -0.51 on the genetic level. These results imply that heavier sheep would have lower crutch cover scores, and would thus have larger crutch bare areas.

Genetic correlations of clean fleece weight with dag scores were negligible (Table 4). Heavier cutting sheep would have higher breech wrinkle scores. Richards *et al*. (2009) in a study on Merino hoggets from the Trangie selection lines reported that they found the largest antagonism between wrinkles and greasy fleece weight. The plainer Folds Minus line was 13% lighter cutting than the control line; while the greasy fleece weight of the Folds Plus line was 6% heavier than the control line. They furthermore reported that clean fleece weight was lower in the reduced wrinkle flock (-10%) but almost unchanged in the increased wrinkle flock. Hatcher *et al*. (2009) also identified unfavourable genetic correlations of 0.56 and 0.34 for total wrinkle score and greasy fleece weight and clean fleece weight, respectively. It thus seems that selection for fewer wrinkles would under some conditions result in a lower greasy and clean fleece weight as a correlated response. Cloete (2002) reported that total fold score was negatively related to clean yield (-0.35) on a genetic basis in an earlier study on these selection lines. These results are consistent with results of Cloete *et al*. (2005) reporting a significant genetic correlation of 0.30 between total wrinkle score and clean fleece weight in the same resource flock used in the present study. Atkins (1980) previously reported that fold development was more closely related to greasy fleece weight than to clean fleece weight. The genetic correlations of clean fleece weight with breech bare areas were in the desired direction, but failed to reach significance.

Genetic correlations with fibre diameter were mostly inconclusive, because they failed to reach a level of double the corresponding standard error (Table 4). Richards *et al*. (2009) reported very little influence on fibre diameter in the Trangie selection lines that were divergently selected for skin wrinkle. Hatcher *et al*. (2009) reported a genetic correlation of 0.31 between total wrinkle score and fibre diameter. Mortimer *et al*. (2009) reported genetic correlation estimates of 0.07 and 0.04 between fibre diameter and neck and body wrinkle scores respectively. However, the absolute direction of the correlations from this study was unfavourable for dag and breech wrinkle scores, suggesting that finer sheep would also have more dags and more wrinkly breeches. The same applied to breech bare areas, as animals with broader fibers would generally have larger bare areas on their breeches. Smith *et al*. (2009b) found moderately negative phenotypic and genetic relations between crutch cover score and fibre diameter of -0.20 and -0.37, respectively. These results also seem to imply that finer sheep would have higher scores for crutch cover, i.e. reduced bare areas on the points. The phenotypic and genetic correlations of breech cover score with fibre diameter reported by Edwards *et al*. (2009) were in the same direction, although weaker, ranging from -0.05 to -0.07 for hoggets and adults respectively.

Breeding values for the selection lines

Averaged breeding values for the respective selection lines suggested favourable correlated responses in breech characteristics in the H line compared to the L line (Table 5). It is further notable that dag scores and breech wrinkle score in the H and L lines were roughly symmetric about zero, suggesting that the change in the upward and downward directions were of the same order. Breeding values for the length and width of the breech bare area also indicated larger bare areas in the H line. However, the response did not seem to be symmetric in this case, with the mean for the L line being closer to zero compared to the L line. The crossbred lines were expected to be intermediate for these traits, as was indicated in Table 5. It is of interest that line differences between H and L line mature ewes for susceptibility to breech strike were reported by Scholtz *et al*. (2010b, Chapter 5), with the H line being less susceptible to breech strike than the L line. No intentional selection was made in terms of either breech strike or any of the indicator traits evaluated in this chapter. It thus seems that divergent selection for reproduction resulted in animals in the H line becoming less wrinkled, with larger bare areas and less dags. The present results are consistent with symmetric genetic changes in total fold score, amounting to -0.12 units per annum in the H line and 0.11 units per annum in the L line (Cloete *et al*. 2005). The results are also consistent with those of Atkins (1980), suggesting that the reproduction of genetically wrinkly sheep is compromised.

Frequency of strikes in the respective selection lines

At 0.033, the frequency of flystrike was relatively low in the present study. Experimental animals were shorn as weaners in September - October and again as yearlings in April - May, and were relatively less attractive to breech strike during this period. All strikes were in the breech area, except for a single poll strike in L line young ram suffering from both breech strike and poll strike. This result is in accordance with other South African literature reporting that breech strike is the most prevalent form of strike under local conditions (Turpin 1947, Howell *et al.* 1978, Cloete *et al*.

2001, Scholtz *et al*. 2010b, Chapter 3). Even at fairly low levels of breech strike in the present study, there is strong evidence that animals with a higher proportion of L line genetics are more susceptible to breech strike than predominantly H line animals. This result is supported by consistent line differences in susceptibility to breech strike in mature ewes (Scholtz *et al*. 2010b). In the latter study it was also found that the H line was less susceptible to breech strike than the L line; with the crosses and backcrosses intermediate as expected.

CONCLUSIONS

It has to be conceded that the data available for the present study were at the minimum required for genetic analysis, as is often found when new traits are analysed. However, results were sufficiently informative to justify the dissemination of the results for scientific scrutiny. All the breech traits that were considered exhibited genetic variation. Genetic correlations among breech traits were generally consistent with expectations and comparable results in literature cited. Genetic correlations of breech traits with live weight and wool traits were mostly favourable or small in magnitude and not significant. The notable exception was the positive genetic correlation between clean fleece weight and breech wrinkle score, suggesting that heavier cutting sheep were more likely to be wrinkly. Selection of Merino sheep for favourable breech traits is thus unlikely to severely compromise hogget production traits if the latter unfavourable genetic correlation could be dealt with.

Secondly, the present results support our earlier findings that selection for an improved reproduction rate results in favourable genetic responses in breech traits and in the frequency of breech strike. Animals subjected to selection for an improved reproduction rate thus seem to be less likely to require chemical treatment for blowfly strike compared to those selected against reproduction. This result is reassuring in an era where robust genotypes, requiring less intervention during routine husbandry procedures, are preferred. The breeding of a robust genotype, capable of good reproduction while also having easy care characteristics, thus seems to be feasible.

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CHAPTER 9

THE EFFECT OF DIVERGENT SELECTION FOR REPRODUCTION ON DAG SCORE, BREECH WRINKLE SCORE AND CRUTCHING TIME IN MERINO HOGGETS

Short communication

THE EFFECT OF DIVERGENT SELECTION FOR REPRODUCTION ON DAG SCORE, BREECH WRINKLE SCORE AND CRUTCHING TIME IN MERINO HOGGETS

Short communication

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ABSTRACT

Merino lines that were divergently selected from the same base population from 1986 to 2009 for their ability to rear multiples were assessed for dag score in autumn and spring, breech wrinkle score and crutching time. These traits were independent of the interaction between selection line and gender ($P > 0.10$), and only main effect means are provided. Animals in the Low (L) line had higher dag and breech wrinkle scores and took longer to be crutched than High (H) line contemporaries (all $P < 0.01$). Expressed relative to H line means, least squares means of L line individuals were respectively 54%, 65%, 42% and 40% higher for autumn dag score, spring dag score, breech fold score and crutching time. Gender effects for dag score were inconclusive, as ewe hoggets were more daggy than rams in autumn, with an opposite trend in spring. The shearer (n = 6) also affected crutching times ($P < 0.01$), with an almost twofold difference in mean crutching time from the quickest shearer (27.7 ± 3.1 seconds) to the slowest shearer (49.4 ± 3.7 seconds). The inclusion of dag score ($P < 0.01$) and breech wrinkle score ($P = 0.07$) as linear covariates in an analysis on crutching time eliminated the effect of selection line. It thus seems if the quicker crutching times of H line animals may be related to line differences for dag score, and to a lesser extent, for breech wrinkle score.

Keywords: reproduction, selection lines, breech strike

INTRODUCTION

Dags are accumulations of faecal material around the tail and crutch (breech) of sheep and are associated with sheep with loose, moist faeces adhering to the wool (Reid and Cottle 1999, Waghorn *et al*. 1999). Dags can accumulate to form large masses that cover the whole rear end of a sheep, and even become dried without falling. Woolly crutches collect wet faeces and urine, especially if there are crutch wrinkles and if the bare skin at the breech has not been stretched by mulesing (Fels 1971). Once dirty, more faeces and urine are collected and patches of skin are kept continuously wet causing skin irritation and 'weeping' of protein-rich fluids from the inflamed skin (Belschner 1937, Watts and Marchant 1977, Watts *et al*. 1978, French *et al*.1996, 1998). Increased dagginess increases the risk of flystrike (Morley *et al*. 1976, Watts and Marchant 1977, Watts *et al*. 1979, French *et al*. 1996). This generalisation also applies at the genetic level (Greeff and Karlsson 2009).

Currently a range of practices are employed to control breech strike; including shearing; crutching; tail-docking; jetting and until recently mulesing. Shearing or crutching removes dags and moist wool; the skin is ventilated and dries out, making it less attractive to flies (Belschner 1953). Mulesing as a breech strike prevention method is now considered to be unethical and it is accepted that it cannot be used anymore.

Counsell (2001) suggested that the cost and frequency of crutching would increase without mulesing in Australia. Daggy sheep are an economic burden to farmers for in addition to direct costs, crutching removes potentially high value wool, which is sold at a heavily discounted price (Meyer *et al*. 1983, Larsen *et al*. 1994). Larsen *et al*. (1995) reported that sheep with increased breech soiling (‘dag’) required significantly more labour to remove the dag prior to shearing. Daggy or stained wool, even when cleaned, carries into the product, causing appearance and performance problems (Scobie *et al*. 1997). Scobie *et al*. (1997) furthermore reported that dags in sheep have detrimental consequences on the saleability of livestock in New Zealand due to the impact on slaughter hygiene. Crutching and shearing were also reported to have animal welfare implications (Scobie *et al*. 1997). Hargreaves and Hutson (1990a) claimed there was no difference in the stressfulness of partial versus complete shearing. They furthermore reported that up-ending (tipping the sheep over in its rump) for shearing was, by itself, a stressful procedure (Hargreaves and Hutson 1990b).

Divergent selection for reproduction in South Africa resulted in lines that differ in susceptibility to breech strike (Scholtz *et al*. 2010b). Line differences in terms of breech and crutch cover scores (Chapter 7) as well as dag scores (Chapter 8) were also reported. This study evaluates the influence of divergent selection for reproduction on crutching time against this background.

MATERIALS AND METHODS

Animals, location and recordings

Two lines of Merino sheep were divergently selected from the same base population from 1986 to 2009, using maternal ranking values for number of lambs reared per joining, as described by Cloete *et al*. (2004). Details of the procedure for the selection of replacements have been reported elsewhere (Cloete and Scholtz 1998, Cloete *et al*. 1998, Scholtz *et al*. 2010b, Chapter 5). Briefly, male and female progeny of ewes that reared more than one lamb per joining (i.e. reared twins at least once) were preferred as replacements in the High (H) line. Replacements in the Low (L) line were preferably descended from ewes that reared less than one lamb per joining (i.e. barren, or loss of all lambs at least once). Depending on average reproduction rates in the lines, and on replacement needs, progeny of ewes that reared one lamb per joining were occasionally selected in either line. Selection decisions were mostly based on ≥3 maternal joinings, especially in the case of rams. Once selected, ewes normally remained in the breeding flock for five joinings. The literature sources listed above may be consulted for additional information on these aspects.

The resource flock studied was maintained at the Elsenburg Research farm. The climate, pastures grown and management of the animals were adequately described by Cloete *et al*. (2004), while lambing and reproduction practices in the breeding flock were described by Cloete and Scholtz (1998). The climate at the experimental site is Mediterranean, with a winter lambing season (June - July). The animals used in this study were the 2006 Merino lamb drop. All animals were tail docked at the third palpable joint at three weeks of age and shorn in September - October as weaner lambs to remove the halo hairs of the lamb fleece. All animals were shorn again in May 2007 as hoggets (11 months old). Hoggets were scored for dags prior to being shorn in May 2007 (autumn dag score). All animals were again scored for dags prior to being crutched in September 2007 (spring dag score) when they were approximately 15 months old using the Visual Breech Scoring System (Australian Wool Innovation Limited 2007). In the allocation of these scores, provision was made for halves when the dag scores for animals were situated between two of the five fixed categories for dags. Soon after being shorn the animals were also scored for breech wrinkle score using the Visual Breech Scoring System (Australian Wool Innovation Limited 2007). During spring crutching the animal's number as well as the time it took to crutch each individual sheep were recorded. The time it took from the first cut till the crutching process was completed (the last cut) was recorded by making use of stopwatches. Six observers, each representing a shearer were used to record the crutching times.

Statistical analyses

Data for dag score, breech wrinkle score and crutching time were subjected to least squares analyses, to account for uneven subclasses (Gilmour *et al*. 2006). Fixed effects included in all the analyses were selection line (H or L line) and gender (ram or ewe), as well as the interaction between these effects. Shearer was included as an additional fixed effect in the analysis of crutching time. Subsequent analyses on crutching time also included spring dag score and breech wrinkle score as linear covariates. Mean crutching times were also derived for categorized dag scores. Because of very low numbers for extreme scores, dag scores below two (1 and 1.5) were pooled with two and those above four (4.5 and 5) were pooled with four for this analysis.

RESULTS AND DISCUSSION

The traits analysed were independent of the interaction between selection line and gender ($P > 0.10$), and only main effect means were thus tabulated.

Animals in the L line had higher dag and breech wrinkle scores and took longer to be crutched than H line contemporaries (all $P < 0.01$). Expressed relative to H line means, least squares means of L line individuals were respectively 54%, 65%, 42% and 40% higher for autumn dag score, spring dag score, breech fold score and crutching time (Table 1).

Table 1. Least squares means (± s.e.) for dag score on two occasions, breech fold score, and crutching time in relation to selection line and gender.

Effect	Number of observations	Dag score		Breech wrinkle score	Crutching time (s)
		Autumn	Spring		
Selection line		**	**	**	**
H line	131	1.47 ± 0.06	1.81 ± 0.09	2.25 ± 0.07	31.7 ± 1.2
L line	18	2.25 ± 0.17	2.99 ± 0.24	3.20 ± 0.20	44.4 ± 3.4
Gender		**	**	0.06	0.06
Ram	75	1.58 ± 0.14	2.79 ± 0.20	2.50 ± 0.17	35.9 ± 2.8
Ewe	74	2.42 ± 0.12	2.01 ± 0.16	2.95 ± 0.14	40.2 ± 2.3

** $P < 0.01$

A line difference for wrinkle score was not unexpected. Cloete *et al*. (2005) reported a similar trend in a previous study on these selection lines for overall wrinkle scores (the sum of neck, body and breech wrinkle scores) where animals from the H line were more plain-bodied than their contemporaries in the L line. Subsequent analyses found near unity genetic correlations between wrinkle scores on different body parts, suggesting that these traits are governed by a largely similar set of genes (Scholtz *et al*. 2010a). McGuirk *et al*. (1981) found bloodline differences in time required to shear rams and ewes, mainly due to skin-fold differences. Scobie *et al*. (2005) reported an up to 20% increase in shearing period, directly related to the number of blows required for sheep with high wrinkle scores. Woolly crutches collect wet faeces and urine, especially if there are crutch wrinkles and if the bare skin at the breech has not been stretched by mulesing (Fels 1971). Wrinkle score is genetically and phenotypically correlated to dag score (Greeff and Karlsson 2009, Smith *et al*. 2009). It therefore stands to reason that animals in the L line took longer to crutch; being wrinkly in the breech area in itself should slow the process down, without the added effect of more dags.

Crutching time was related to dag score ($P < 0.01$), with mean crutching times of 30.3 ± 3.8 seconds for dag scores of 2 and lower, 32.1 ± 2.6 seconds for dag score 3 and 50.9 ± 2.8 seconds for dag scores of 4 and higher. The effect of regression of crutching time on dag score indicated that an increase of 1 in dag score would result in an increase (b ± s.e.) of 7.4 ± 1.0 seconds in crutching time. A corresponding increase of 1 for breech fold score was associated with an increase of 2.3 ± 1.2 seconds in crutching time. Horton and Iles (2007) reported that the most important factor affecting crutching period in animals at 8 months of age was dag score in a study on 8 month old mulesed and unmulesed Merinos. Horton and Iles (2007) used a zero (no dag) to 5 scale, and reported a significant increase in crutching period for each unit increase in dag score above 1 and very severe effects at dag scores 4 and 5, which appears to be fairly consistent with the present results. The literature also reports that the presence of dags results in the time taken to crutch a lamb being doubled (Scobie *et al*. 1999). It is noted that bare area could also have an influence on crutching time, but it was not studied in this chapter.

Gender effects for dag score were inconclusive, as ewe hoggets were more daggy than rams in autumn, with an opposite trend in spring (Table 1). In a study on scouring mulesed sheep, Morley *et al*. (1976) reported that wether lambs tended to be more susceptible to faecal soiling and breech strike than ewes. Horton and Iles (2007) reported that fewer ewes than wethers required crutching in a mixed–gender group. Scobie *et al*. (2005) in a study on Coopworth lambs reported that a gender effect became apparent, with the wethers developing a significantly higher mean dag score. They ascribed the reason for a higher accumulation of dags in the males to the difference in the bare area around the anus versus the area around the anus and vulva. In contrast, Meyer *et al*. (1983) reported that the incidence of dags varied widely over ages and seasons with the highest incidence generally observed among ewes at tail-docking. While the tendency to dagginess in sheep is partly under genetic control (Meyer *et al*. 1983, Morris *et al*. 1997), several factors, including intestinal parasites (McEwan *et al*. 1992), some fungal toxins (Fletcher and Sutherland 1993), low tannin feed and high quality, high moisture content feed have been associated with dag formation. It is thus clear that the literature is undecided about the direction of the gender effect on breech dagginess. The conflicting results for autumn and spring dag scores should be seen against this background.

Shearer (n = 6) also affected crutching times ($P < 0.01$), with an almost twofold difference in mean crutching time from the quickest shearer (27.7 ± 3.1 seconds) to the slowest shearer (49.4 ± 3.7 seconds). In contrast to this result, Horton and Iles (2007) remarked on a small difference in crutching time between the two shearers from their study. Shearing teams from neighboring Lesotho and mainly the Eastern Cape Province are predominantly used in South Africa. These teams have a high turnover in terms of human resources. Therefore it is speculated that experience and training within such teams might differ markedly, thus influencing crutching time in the present study.

The inclusion of dag score ($P < 0.01$) and breech wrinkle score ($P = 0.07$) as linear covariates in an analysis on crutching time eliminated the effect of selection line (least squares means of 33.0 ± 1.0 seconds for the H line and 35.4 ± 3.1 seconds for the L line; $P = 0.40$). It thus seems if the quicker crutching times of H line animals may be related to line differences for dag score, and to a lesser extent, to breech wrinkle score. It thus seems if the welfare of the wrinklier and daggy L line hoggets may have been compromised as far as the effort needed for crutching was considered.

CONCLUSIONS

Apart from the obvious benefits of a Merino line with improved reproduction upon farm profitability (Olivier 1999), plainer and highly reproductive Merinos also seem to be more preferable from a welfare perspective. Previous results have indicated that H line animals were less likely to be affected by breech strike (Scholtz *et al*. 2010b). The present study indicate that the welfare of H line animals were also less likely to be compromised during shearing than that of their L line contemporaries. These results all contribute positively to a quest for the breeding of an ethically and economically sustainable strain of Merinos, as envisaged by Scobie *et al*. (1997, 1999), James (2006) and Horton and Iles (2007). Apart from this, a shorter crutching time would also result in the time shearing gangs are resident on the farm being shortened. In South Africa this would lead to a reduced expense in the sustenance of the shearers, which generally is the responsibility of the farmer.

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CHAPTER 10

GENERAL CONCLUSIONS AND FUTURE PERSPECTIVES

GENERAL CONCLUSIONS AND FUTURE PERSPECTIVES

The focus of this dissertation is strongly on genetic improvement of sheep for resistance to breech strike as a major component of an Integrated Pest Management (IPM) program. Other components (some of which were not explicitly studied but were reviewed in Chapter 2), or where inconclusive outcomes were obtained (see Chapters 3 and 4), are also included. Seeing that methods such as crutching; fly trapping; shearing time, etc. (Chapter 3) controlled little variation in breech strike, it is reasonable that genetic prospects be emphasised. Possible impacts on breech strike due to other practices can be inferred from the literature in Chapter 2.

Individual chapters from this thesis already carry conclusions. This chapter therefore summarizes the main objectives and outcomes generated from this study. It will also provide readers with suggestions regarding the future management of blowfly strike, and more specifically breech strike, in the South African small stock genetic resource. This study reports on managerial and breeding components that could potentially be used in an Integrated Pest Management (IPM) program for reduced susceptibility to flystrike under South African conditions.

PART I: MANAGERIAL COMPONENTS TO IPM

It was clear from the survey in Chapter 3 that breech strike is the major form of strike in the Western Cape region. This tendency was confirmed in the studies on experimental genetic resource flocks discussed in Chapters 5 and 8. Mulesing was again demonstrated to be an effective control method for breech strike in the survey. With the termination of mulesing as an acceptable management practice, this chapter highlights the need for alternative methods to be used for blowfly control. It is notable that other initiatives that could add to blowfly control as noted in Chapter 3 failed to have the same marked impact on blowfly strike that mulesing had. Indicator traits associated with blowfly strike in Chapter 3 included the presence of Dermatophilosis and wool colour score. Since none of the management practices in use on the farms surveyed were sufficient to guarantee complete blowfly control when evaluated on their own, an IPM approach should be considered. Sustainable ectoparasite control is an important aim for the sheep industry. The recent move towards pesticide residue minimization also favours an IPM approach. An IPM approach for the control of blowfly strike should include components of sheep husbandry, farm management; selective breeding and strategic insecticide usage. One or more environmentally friendly insecticides are a prerequisite in an IPM programme for the strategic or salvage treatment of long wool sheep (Levot *et al*. 2002, Lowe *et al*. 2006). Evaluation of products suitable for this purpose is thus indicated. More research on the integration of the components of IPM listed above is also needed.

An indirect method to control blowfly is to reduce dagginess of sheep thereby making them less attractive for breech strike. Crystals derived from *Aloe* spp. were assessed in Chapter 4 for their potential use as an herbal anthelmintic to control breech strike indirectly. Results from Chapter 4 showed no reduction in the parasite burden when treated with *Aloe.* Dag scores were accordingly unaffected by *Aloe* treatment. The lack of an effect of the *Aloe* treatment could possibly be ascribed to an inadequate way of administration the aloe solution or to an ineffective rate of dosage for the gastrointestinal challenge faced by the animals tested. Alternative administration methods or different dosages could therefore possibly be evaluated in future. Furthermore a change in properties caused by the heat treatment during the initial preparation process of the *Aloe* crystals could also have contributed to the lack of effect, but such a deduction is speculative.

In a study by Scholtz *et al*. (2000), evaluating the Lucitrap®, it was clear that blowfly numbers in the Rûens area tend to be very high and this probably led to mulesing being routinely practiced on many of the properties in this area. Peak blowfly periods in this part of the Western Cape are early spring (October) and late summer/autumn (April/May) (Scholtz *et al*. 2000). In view of the phasing out of the Mules operation in South Africa, it was argued that shearing prior to one of these periods and crutching prior to the other could minimize potential problems with flystrike. The local industry has adapted to the situation by adopting generally shorter shearing intervals. According to R. Scott (BKB, P.O. Box 2002; Noordeinde 6056, South Africa or Robert.Scott@bkb.co.za, personal communication), between 60 – 65% of the wool producers in the Rûens area shear twice a year (i.e. after a 6-month interval), while 30 – 39% shear after a wool growth period of eight months. Less than 1% of the wool producers are shearing their sheep with a wool growth period of a full year (i.e. 12 months). With the practice of shearing shorter wool, crutching as a management practice to reduce breech strike has been eliminated. A predominantly spring lambing season is used with 60% of the producers lambing their sheep when there is grazing available after the winter rains. On these farms shearing is done prior to lambing leaving the sheep with short wool during the high risk blowfly strike period. In a six month shearing cycle, shearing is again done prior to the peak blowfly period in April/May reducing the risk of blowfly strike significantly. During periods of high risk or when other farming activities do not allow intensive managing of the flocks, preventative treatment with systemic ecto-parasiticides is done. With the 40% of producers shearing at 8-montly intervals, management differs from farm to farm, making it difficult to discern a definite pattern.

South African producers are very fortunate in the sense that larger, more reproductive lines of Merino sheep already exist. Over time the demand for meat has favoured the selection of plain-bodied animals, which have faster growth rates and higher lambing percentages (Olivier and Cloete 1998, Poggenpoel and van der Merwe 1987).

PART II: BREEDING COMPONENTS TO IPM

Divergent selection for reproduction (defined as the ability of ewes to rear multiple offspring) resulted in lines that differed markedly for their susceptibility to breech strike as a correlated effect (Chapter 5). The line selected for reproduction (High line or H line) was more resistant to breech strike than the line selected against reproduction (Low line or L line). Breed and/or line differences are often regarded as indicative of genetic variation in a specific trait. It was concluded that these results support recent reports of genetic variation in susceptibility to breech strike in Merino populations (James 2006, Murray *et al*. 2007, Edwards *et al*. 2009, Greeff and Karlsson 2009, Richards *et al*. 2009, Smith *et al*. 2009 a, b). It follows that selection could thus be used to retain animals that are less susceptible to breech strike, provided that an adequate blowfly challenge prevails. However the unpredictability of breech strike, the widespread use of prophylactic treatments such as jetting and crutching, as well as animal welfare concerns under adequate challenge conditions, adds to arguments for indirect selection instead of direct selection. Indicator traits such as scores for wrinkles, dags, urine stain, breech bareness and wool colour have, among others, recently been identified to play an important role in susceptibility to breech strike (James 2006, Murray *et al*. 2007, Edwards *et al*. 2009, Greeff and Karlsson 2009, Smith *et al*. 2009a, b). Excessive skin folds have also been conclusively linked to a higher susceptibility to breech strike in the early years of blowfly research (Seddon 1931, Seddon *et al*. 1931, Joint Blowfly Committee 1933).

Following on from the line differences in Chapter 5, Chapter 6 reported genetic (co)variances between wrinkle scores and the absence of breech strike in mulesed and unmulesed Merino sheep. This chapter suggested that breech strike on the underlying scale is partly under genetic control. It is furthermore evident from the results from Chapter 6 that indirect selection levelled against skin wrinkle scores could play a role in reducing the susceptibility of sheep to breech strike in unmulesed sheep. In this chapter, the significant genetic variation for absence of breech strike remaining in mulesed sheep hints at traits not associated with wrinkles and bare breeches (which are arguably being strived for during the Mules operation) also being important in breech strike resistance genetics. The results from Chapter 6 suggested that direct selection for resistance to breech strike would be successful under adequate challenge conditions. However, it was conceded that the incidence of breech strike would have a telling influence upon heritability on the observed scale and therefore the success of direct selection. Because of this, as well as reasons listed previously, it was argued that indicator traits thought to be associated with breech strike should also receive attention, as the basis for indirect selection.

Merino sheep divergently selected for reproduction rate were assessed further to try to understand the underlying cause of the difference in susceptibility of the H and L lines to breech strike (as demonstrated in Chapter 5). It was demonstrated that the animals in the H line displayed desirable breech and crutch characteristics compared to contemporaries selected against reproduction (L line) in animals available in 2009 (Chapter 7). This generalisation held true for mature reproducing ewes as well as for two-tooth hoggets. Dag scores were accordingly improved in hoggets (Chapter 7). The latter line difference in dag scores as well as breech wrinkle score was supported in a separate study on hoggets that were born in 2006 (Chapter 9). Results from Chapter 9 furthermore indicated that H line hoggets took a substantially shorter time to be crutched than their L line contemporaries. Based on literature suggesting that husbandry actions like shearing and crutching are stressful to sheep (Hargreaves and Hutson 1990a, b), this outcome suggested that the welfare of H line animals was less likely to be compromised during shearing than that of their L line contemporaries.

In a further study, it was shown that autumn and spring dag scores, breech wrinkle score as well as the depth and width of bare areas were all heritable in the lines divergently selected for reproduction, estimates of heritability ranging from 0.21 for autumn dag score as well as for depth of bare area to 0.53 for breech wrinkle score (Chapter 8). Genetic correlations among breech traits were generally favourable as would have been expected. Yearling live weight was mostly favourably related to breech traits on the genetic level. The only genetic correlation of breech traits with objective wool traits that would cause concern was a positive correlation of 0.47 between clean fleece weight and breech wrinkle score.

In support of the phenotypic line differences in indicator traits for breech strike reported in Chapters 7 and 9, it was shown in Chapter 8 that averaged breeding values for dag scores and breech wrinkle score in the H and L lines were roughly symmetric about zero, indicating substantially less dags and plainer breeches in the H line. Breeding values for the depth and width of the breech bare area responded in much the same way, indicating larger bare areas in the H line. These results all contributed to a hypothesis that selection for reproduction altered the breech characteristics of the Merino sheep used in the present study, thereby making them less susceptible to breech strike. This argument was supported by a genetic trend in another resource flock indicating that a line selected against barrenness and rearing failure became more resistant to breech strike with time (Scholtz *et al*. 2010a, Chapter 6).

It needs to be stated that meat contributes substantially to the income of wool farmers in South Africa (Londt and McMaster 1998). This demand for meat has favoured the selection of animals which have faster growth rates and higher lambing percentages (Poggenpoel and van der Merwe 1987, Olivier and Cloete 1998, Olivier 1999). The results provided above contribute to growing evidence of a favourable genetic association between a high reproduction rate and a reduced susceptibility to breech strike in wool sheep. Another spin-off from a higher lambing percentage is that the greater numbers available for flock replacements offers the potential for faster genetic gain in a flock (Baillie 1979).

Finally, it is important to note that results from this study contribute positively to a quest for the breeding of an ethically and economically sustainable strain of Merinos, as envisaged by various authors (Tierney 1978, Scobie *et al*. 1997, 1999, 2007, Collins and Conington 2005, James 2006, Horton and Iles 2007, Greeff and Karlsson 2009). Considering the phasing out of the Mules operation in wool sheep producing countries, the outcomes from this study are very positive and indicative of life after mulesing. Breech strike is associated with large production, financial and welfare losses. Therefore, indirect selection and direct selection under certain circumstances may become important components of an integrated blowfly IPM strategy. A genetic solution to breech strike control is attractive, as it is potentially permanent, cumulative, does not involve the increased use of chemicals; may ultimately reduce labour inputs and is attractive from animal welfare, ethical, economic as well as sustainability perspectives (Russell 1994, Tellam and Bowles 1997, People for the Ethical Treatment of Animals 2004, Plant 2006, Lee and Fisher 2007).

RECOMMENDATIONS

Against this background, the following recommendations are made:

- It is conceded that other areas in the country and those properties not making use of a shorter wool shearing interval would differ in terms of blowfly strike risk. The integration of managerial aspects of an IPM program should receive further attention under South African conditions, especially for those areas and properties. Management options can include aspects like strategic prophylactic chemical treatment, pasture management, trapping, crutching and dagging. Although the results in Chapter 3 were inconclusive in this respect, it can be advised on research elsewhere, and reviewed in Chapter 2, that these practices do have value in an IPM program for blowfly strike control.
- Although not studied explicitly in this research it should be noted that environmentally friendly insecticides for the salvage treatment of long-wool sheep during fly wave conditions should be developed. In cases where such products are already available after being developed elsewhere, such products should be evaluated under local conditions.
- Further research would be useful to elucidate the specific role of individual indicator traits for breech strike in specific environments for inclusion in integrated blowfly control programmes. However, based on the advantage brought about by selection results reported on here and elsewhere, it can be applied with immediate effect.
- Although outcomes from this study are extremely encouraging, it needs to be stated that most results are based on relatively small databases. Although recording should continue to provide industry with more accurate genetic parameters, industry in the mean time can start applying current knowledge to breed sheep to reduce flystrike.
- Although further studies are needed to fully comprehend the impact of selection for breech strike resistance and associated individual traits, sufficient evidence have been presented to indicate that these selection procedures would indeed be successful under South African conditions. It is therefore recommended that selection commence immediately by the culling of animals suffering from breech strike repeatedly and also by favouring less wrinkly animals and animals with larger bare areas and lower dag scores. Based on the results this should have a positive influence on reproduction and liveweight while no conclusive deleterious effects could be found for wool traits (such as fleece weight, fibre diameter, staple strength).
- Although there appears to be significant opportunities to reduce the susceptibility of Merinos to breech strike by genetic means, much of the information required for a full assessment is not presently available. More information is needed on the relationship

between production traits and the indicator traits listed for breech strike to be able to estimate robust genetic and phenotypic parameters for the design of efficient breeding programs. Such parameters would allow the derivation of appropriate selection indexes, based on economic principles, to be applied during selection in industry flocks.

- Identification of animals with extreme breeding values for indicator traits from within the Merino population would seem to be a possible point of departure for genomic studies on the indicator traits associated with breech strike. It will be particularly helpful if (some of) the required traits are determined by genes with a major or relatively large effect. The structure of the resource populations used in the present study would allow genomic studies with minimal adaptation.

In conclusion, the study has shown definite opportunities for the alleviation of the problem of breech strike, although further research is still needed. It thus presents the scientific community with ample opportunities to refine and integrate existing strategies discussed in this document. As this document is by no means complete, there are still other avenues not touched upon that could also be exploited as part of blowfly IPM. When assessed against this background, there does not seem to be a need for an air of doom and gloom in post-mulesing era. The local industry already appears to have adapted by the shortening of the shearing cycle. This intervention is facilitated by shearing costs being relatively low in South Africa. The industry could therefore look with confidence at a rosy future, while running sheep that are better adapted to the environment in which they have to thrive and perform in.

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CHAPTER 11

DESCRIPTIVE TERMINOLOGY

DESCRIPTIVE TERMINOLOGY		
1.	**IPM**	Integrated Pest Management (IPM) is the systematic approach of the control of a problem organism and relies on the use of more than one and preferably several methods acting synergistically. An IPM program includes consideration of animal welfare, environmental, economic and occupational health and safety concerns.
2.	**Blowfly strike**	Blowfly strike (ovine myiasis) is the cutaneous infestation of sheep by the larvae of blowflies The adults are free-living and the larvae are parasitic maggots, which develop in the tissue of their host. The feeding activity of the larvae causes extensive tissue damage and leads to considerable distress to the struck animal, and if untreated, death in 3 - 6 days from the onset of the first strike. Secondary bacterial infection often occurs and the animal may die of septicaemia or the absorption of toxins from liquefied body proteins.
3.	**Predisposition of sheep to flystrike**	Flystrike in sheep does not occur by chance, but it is essentially due to the inherent attractiveness of a susceptible animal. Flystrike can result from a range of predisposing characters, e.g. dermatophilosis; fleece-rot, dags, urine stain, wounds, footrot lesions, adhering afterbirth etc.
4.	**Breech strike**	Breech strike is a collective term for all strikes occurring on the crutch and tail region of sheep and is considered the most common form of strike in South Africa, Australia, New Zealand and England. Breech strike occurs when the wool in the breech area becomes soiled with faeces, urine and sweat with the subsequent development of dermatitis.
5.	**Mules operation**	Mulesing is a drastic surgical operation used to reduce the number of skin folds (wool bearing skin) from the breech of lambs, allowing the natural bare area to stretch considerably around the perineum. The resultant stretched bare area does not produce wool, limiting the retention of faeces and/or urine, thereby making the breech less attractive to flies and substantially lowering the incidence of breech strike.
6.	**Divergent selection for reproduction**	Reproduction, defined as number or total weight of lambs weaned per breeding ewe per year (or over her lifetime), is considered to be the most important trait in the South African sheep industry. Indications against selection for reproduction are the composite nature of a trait defined as above, a low heritability, expression only in females, and recording at a relatively advanced age. Based on the economic value of reproduction, a divergent selection experiment was launched in the 1980's in South African Merino sheep. This regime resulted in marked, but slightly asymmetric, genetic responses for reproduction, responses

		in the upward direction being approximately double those in the downward direction.
7.	**Selective breeding under natural challenged conditions**	To identify sheep that are genetically resistant to a pathogen the sheep must be exposed to the organism in a natural state to allow the organism to challenge the sheep. The response to selection is highest if a trait is selected for directly. However, selecting directly for blowfly strike resistance is often not efficient because of the sporadic nature of the condition and the associated production losses. A further limiting factor is the fact that nearly all Merinos are treated by some preventative measure (e.g. crutched; jetted; mulesed) whereby they are protected from becoming infected. A challenge based selection method can potentially become vary labor intensive to manage if it was to avoid serious animal welfare issues. The alternative is to identify those characteristics that make a sheep susceptible (indicator traits) and then select for or against them.
8.	**Indicator trait – wrinkles**	The raised folds on the skin of Merino sheep and related breeds are variously called wrinkles, ribs, folds or pleats and the sheep carrying them are referred to as wrinkly, developed or pleated. Sheep that are free of wrinkles are sometimes called plain-bodied or flat-skinned. The major predisposing factor for breech strike is the number and location of caudal folds/wrinkles in the breech area. Breech strike occurs when the wool in the breech area becomes soiled with faeces, urine and sweat with the consequent development of dermatitis.
9.	**Indicator trait - breech bareness**	The amount of natural bare skin around the perineum and breech area, in particular the width and depth of skin below and surrounding the vulva or anus. Greater bareness should afford sheep with a reduced likelihood to be affected by breech strike.
10.	**Indicator trait - Dags**	An accumulation of faecal material around the tail and crutch (breech) of sheep are called dags. The role of faecal staining in predisposition to breech strike is well established.

CHAPTER 12

SUMMARY/OPSOMMING

SUMMARY

Title:	**Components of an Integrated Pest Management (IPM) program for the control of the sheep blowfly *Lucilia cuprina* under South African conditions.**
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Degree:	**Ph.D.**

The study includes separate papers, which are all linked by their emphasis on the control of blowfly strike, and breech strike in particular. This summary is intended to provide readers with a broad overview of the outcomes of the study.

Part I. Management options

Chapter 3 dealt with a survey on the prevalence of blowfly strike, and the methods used to combat blowfly strike, in the Rûens area of South Africa. It was clear from the survey that breech strike is the major form of strike in the Western Cape. Mulesing was once again demonstrated to be an effective control method for breech strike. With the termination of mulesing as an acceptable management practice, this chapter highlights the need for alternative methods to be used for blowfly control. Although useful from an IPM perspective, other initiatives that could add to blowfly control failed to have the same marked impact on blowfly strike that mulesing had.

Chapter 4 reports on the effect of regular treatment with crystals derived from *Aloe* spp for potential use as a natural anthelmintic in yearling Merino progeny. The short-term effect of aloe treatment was also considered. Results showed no reduction in the parasite burden when sheep were treated with *Aloe.* The contribution of this treatment to blowfly IPM is thus limited.

Part II. Breeding options

Divergent selection for reproduction (defined as the ability of ewes to rear multiple offspring) resulted in lines that differed markedly for their susceptibility to breech strike as a correlated effect (Chapter 5). The line selected for reproduction (High line or H line) was substantially more resistant to breech strike than the line selected for low reproduction (Low line or L line).

Chapter 6 reported genetic (co)variances between wrinkle scores and the absence of breech strike in mulesed and unmulesed Merinos. This chapter suggested that breech strike on the underlying

scale is partly under genetic control. Indirect selection levelled against skin wrinkle could play a role in reducing the susceptibility of sheep to breech strike in unmulesed sheep only. The significant genetic variation for absence of breech strike remaining in mulesed sheep hints at traits not associated with wrinkles and bare breeches (which are arguably being strived for during the Mules operation) also being important in breech strike resistance genetics.

In Chapter 7 subjective scores for dags, breech cover, crutch cover and belly quality were recorded for mature and maiden ewes in the divergently selected lines in an attempt to understand the reasons for the lower susceptibility to breech strike in the H line. Animals in this line displayed desirable breech and crutch characteristics compared to contemporaries selected against reproduction (L line). This generalisation held true for mature reproducing ewes as well as for two-tooth hoggets. Dag scores were accordingly improved in hoggets in the H line.

In a further study (Chapter 8) it was shown that autumn and spring dag scores; breech wrinkle score as well as the vertical and horizontal breech bare areas were all heritable in the lines divergently selected for reproduction. Genetic correlations among the breech traits were generally favourable. Yearling live weight was favourably related to breech traits on the genetic level. The only genetic correlation of breech traits with fleece traits that would cause concern was a positive correlation between clean fleece weight and breech wrinkle score. Derived breeding values in this chapter confirmed substantial genetic differences for both dag scores, breech wrinkle score and breech bare area in favour of the H line.

Results from Chapter 9 indicated that H line hoggets took substantially shorter time to be crutched than their L line contemporaries, indicating welfare benefits in favour of the former line.

Implications

The study has shown definite opportunities for the alleviation of breech strike and presents the scientific community with ample opportunities to refine and integrate existing control measures in a comprehensive IPM strategy. However, further research is needed to reach this objective.

OPSOMMING

Titel: **Komponente van ‘n Geïntegreerde Plaagbeheer Bestuursprogram vir die beheer van die skaapbrommer *Lucilia cuprina* onder Suid-Afrikaanse toestande.**
Naam: **Anna J. Scholtz**
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Mede-studieleiers: **Prof. J.B. Van Wyk**
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Fakulteit: **Natuur- en Landbouwetenskappe**
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Department: **Sentrum vir Volhoubare Landbou en Landelike Ontwikkeling**
Graad: **Ph.D.**

Die proefskrif bestaan uit aparte artikels, wat almal onderling met mekaar verband hou en wat die belangrikheid van die beheer van brommeraanvalle, en meer spesifiek broekaanvalle, beklemtoon. ‘n Opsomming van die artikels het dus ten doel om aan die leser ‘n breë perspektief oor die uitkomste van die studie te voorsien.

Deel I. Bestuursopsies

Hoofstuk 3 handel oor ‘n opname na die voorkoms van en die metodes wat gebruik word om brommeraanvalle te beheer in die Rûens gebied van Suid-Afrika. Dit was duidelik uit die ondersoek dat broekaanvalle die belangrikste vorm van brommeraanvalle is. Ironies genoeg is dit weereens bewys dat die Mules operasie ‘n baie effektiewe metode vir die beheer van aanvalle in die broek is. Met die uitfassering van die Mules operasie as ‘n aanvaarbare bestuursmaatreël, beklemtoon hierdie hoofstuk die nodigheid van alternatiewe brommerbeheermaatreëls. Gesien in die lig van bruikbaarheid in ‘n Geïntegreerde Plaagbeheer Bestuursprogram (GPB), het geen van die ander beheermetodes wat aangewend word dieselfde merkbare impak gehad as die Mules operasie nie.

Hoofstuk 4 verskaf inligting oor die effek van die gereelde gebruik van Aalwyn kristalle as ‘n natuurlike interne parasiet wurmmiddel in jaaroud Merinos. Die korttermyn effek van Aalwyn behandeling is ook ondersoek. Geen verlaging in die parasietlading kon waargeneem word nie. Die bydrae van hierdie behandeling tot ‘n GPB vir brommers is dus beperk.

Deel II. Telings opsies

Seleksie vir reproduksie (gedefinieer as die vermoë van ooie om meerlinge groot te maak) het tot gevolg gehad dat lyne wat uiteenlopend geselekteer is vir reproduksie beduidend van mekaar verskil het ten opsigte van hulle ontvanklikheid vir brommeraanvalle, as ‘n gekorreleerde effek

(Hoofstuk 5). Die lyn geselekteer vir reproduksie (Hoë lyn of H lyn) was beduidend meer weerstandbiedend teen broekaanvalle as die lyn geselekteer teen reproduksie (Lae lyn of L Lyn).

Hoofstuk 6 verskaf inligting oor genetiese (ko)variansies tussen punte vir broekplooie en die afwesigheid van broekaanvalle in skape wat ge'mules" en nie ge'mules' is nie. Hierdie hoofstuk dui aan dat broekaanvalle op die onderliggende skaal gedeeltelik onder genetiese beheer is. Indirekte seleksie gemik teen broekplooitellings om die vatbaarheid van skape vir broekaanvalle te verminder, kan alleenlik 'n rol speel by skape wat nie ge'mules' is nie. Die beduidende genetiese variasie vir die afwesigheid van broekaanvalle wat oorbly in skape wat ge'mules' is, dui daarop dat ander eienskappe wat nie verwant is aan plooie en oop areas in die broek nie (waarna gestreef word met die Mules operasie), ook belangrik is in die genetika oor vatbaarheid vir broekaanvalle.

In Hoofstuk 7 is subjektiewe punting vir misklosse; wolbedekking in die broek- en mik areas; sowel as kwaliteit van wol op die pens aangeteken vir volwasse en onvolwasse ooie in die lyne wat geselekteer is vir uiteenlopende reproduksie. Die doel van die studie was om die redes vir laer vatbaarheid in broekaanvalle in die H lyn vas te stel. Diere in laasgenoemde lyn het gunstige broek- en mikeienskappe gehad in vergelyking met diere in die lyn wat geselekteer is teen reproduksie (L lyn). Hierdie veralgemening het gegeld vir volwasse ooie sowel as tweetand ooie. Misklos punte is dienooreenkomstig verbeter in tweetand ooitjies in die H lyn.

In 'n verdere studie (Hoofstuk 8) op die seleksielyne wat uiteenlopend vir reproduksie geselekteer is, word aangetoon dat subjektiewe punting van broekplooie en misklosse in die herfs en lente; sowel as die vertikale en horisontale metings van die wolvrye broekarea oorerflik is. Genetiese korrelasies tussen hierdie broekeienskappe was in die algemeen gunstig. Liggaamsgewig op jaaroud ouderdom is op genetiese vlak gunstig verwant aan die broekeienskappe. Die enigste genetiese korrelasie tussen broekeienskappe en vageienskappe wat rede tot kommer veroorsaak, is die positiewe korrelasie tussen skoonvaggewig en broekplooi punting. Beraamde teelwaardes bevestig merkbare genetiese verskille ten gunste van die H lyn vir beide misklos- en broekplooi punte; sowel as vir oop areas in die broek.

Resultate uit Hoofstuk 9 dui daarop dat dit korter neem om tweetand skape in die H lyn te mikskeer as in die L lyn, wat voordele vir die H lyn, in terme van welsyn, inhou.

Implikasies

Hierdie studie dui op definitiewe geleenthede om broekaanvalle te verminder en verskaf die wetenskaplike gemeenskap met verskeie opsies om bestaande beheermaatreëls te verfyn en te integreer in 'n omvattende GPB strategie. Verder navorsing is egter nodig om hierdie doel te kan bereik.

Soli Deo Gloria!