FINAL REPORT

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AWI Project Manager:	Geoff Lindon
Contractor Name:	CSIRO
Prepared By:	Dr Jen Smith
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Breeding for breech flystrike resistance - Phase 3

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1. EXECUTIVE SUMMARY

This work followed 2 previous Projects on breech flystrike genetics - Project EC940 (2005-2010) and Project WP468 (2010-2012).

The period of the current project (2012-2015) focussed on a) continued development and recording of the Armidale breech strike genetics resource flock resistant and susceptible selection lines, including to improve precision of genetic parameter estimates, b) conduct of an evaluation of tail docking methods in relation to later age breech strike, and c) to supply biological material (skin and wool samples) to the WA team.

The flock is fully pedigreed, and comprehensively phenotyped for a wide range of breech traits and production traits. Through the strategic use of industry link sires and inclusion in Merino Select, this flock makes a valuable contribution for benchmarking and encouragement of uptake of breeding for breech strike resistance in industry.

Interim phenotypic and genetic parameters for breech strike, flystrike indicators, and production traits in this flock have been reported in earlier Milestone and Final reports to AWI, and in the scientific literature. This report includes revised phenotypic and genetic parameters using the entire dataset. In summary, results are:

- Breech strike at weaner, yearling and adult age has low to moderate heritability (0.16 – 0.26).
- Breech strike of weaners, yearlings and adults have moderate to high genetic correlations (0.26 – 0.92).
- Many potential indirect selection criteria for breech strike have been evaluated over the course of these projects. Breech wrinkle, dag, and breech cover have suitable combinations of phenotypic and genetic parameters which make them appropriate candidates as indirect selection criteria for breech strike.
- Merino Select has provided across-flock ASBV's for these three traits since 2009 and they remain relevant and suitable to aid selection for improved breech strike resistance in Merinos.
- The most suitable indirect selection criterion for breech strike for fine wool sheep in the summer rainfall environment is breech wrinkle (heritability 0.36, genetic correlation with breech strike 0.42, average of young age parameters).
- There are some moderately unfavourable phenotypic and genetic correlations between indirect selection criteria for breech strike and economically important production traits. The largest, and most important of these are the genetic correlations between adult clean fleece weight and breech wrinkle (0.38) and between breech wrinkle and fibre diameter (-0.23). It is important to note that while these associations are not so strong as to preclude concurrent genetic gain in both breech strike resistance and fleece traits the unfavourable relationships are a significant hurdle in the adoption of breeding objectives for low wrinkle low fibre diameter, wool orientated Merinos.
- There are many favourable phenotypic and genetic correlations between the indirect selection criteria for breech strike and production traits, particularly those involving body weight and variation in fibre diameter.
- Earlier recommendations to industry regarding inclusion of breech strike into Merino breeding programs generally remain unchanged from earlier iterations of results. That is, the indirect selection criterion of choice should be dependent upon the individuals, sheep type, breeding objective, and production environment (climate).

An evaluation of the effect if tail docking method on later-age breech strike was conducted. There is no consistent evidence of significant differences in breech strike rates arising from any of the four tail-docking methods evaluated.

Wool and tissue (skin) samples have been supplied to UWA to assist in their aims to identify other factors influencing risk of flystrike (i.e. odour)

Genomic material and phenotype data from the Armidale flock was supplied to a separate study of breech strike genomics (CSIRO and AWI)

Pedigree, fixed effects and phenotype data for the 2012 and 2013 drop Armidale progeny were supplied to NSW DPI for a separate study of post-weaner fleece traits.

2. INTRODUCTION/HYPOTHESIS

The previous breech strike genetics projects (AWI Projects EC940 (2005-2010) and WP468 (2010-2012)) demonstrated that there is genetic variation in breech strike, and that indicator traits such as breech wrinkle, breech cover, dag and urine stain are phenotypically and genetically correlated with breech strike. These known indicator traits explain some, but not all, of the variation in breech strike.

Evidence from the WA flock, where there were small differences between the selection lines (Resistant and Susceptible) in breech traits, but large differences in breech strike rates, suggests that there may be other inherent factors contributing to breech susceptibility. Previous published research by others on sheep and blowflies; cattle and horn flies; and an earlier AWI study using detector dogs, indicate odour may play a role. Hence, the WA team, in a separate study being conducted by the University of Western Australia (UWA), aim to investigate the role of odour in attracting or repelling blowflies to/from sheep. The Armidale team's contribution to this activity is simply to supply to WA, wool and tissue samples, and details of the phenotypes of the animals from which they came.

During the current Project period, the Armidale flock was used as a continuing resource for both genetic and management-related breech strike control. In addition to the odour studies conducted by the WA team, activities included:

a) Supply of data and genetic material for AWI project WP550, Breech strike genomics, submitted September 2014
b) Evaluation of tail docking methods and effect of docked tail length on lifetime breech strike resistance
c) Continuation of data collection for improved genetic parameter estimates for breech strike and indicator traits, and industry genetic linkage for these traits
d) Contribution of data for a study of the correlation between post-weaner and adult production traits. This study was conducted by NSW DPI.

3. LITERATURE REVIEW

Breech strike is a major animal health issue for Australian Merino sheep. Historically, the practice of mulesing has been a highly effective method of reducing breech strike (Morley and Johnstone 1983; Beveridge 1984). However, in recent years, the welfare implication of mulesing has prompted the sheep industry to investigate and evaluate alternative means of breech strike control, many of which were reviewed by Tell am and Bowles (1997) and James (2006).

Selective breeding to reduce breech strike is one strategy to reduce the incidence of breech strike in unmulesed sheep and is widely viewed to be an appropriate long-term alternative to mulesing. It is likely that genetic improvement of breech strike resistance in sheep is possible through selection on indicator traits such as breech wrinkles, bare area around the perineum, and dags (faecal soiling of the breech region).

Earlier studies of Australian Merinos indicated potential for changing the degree of wrinkle on the neck, body and breech through selective breeding (Brown and Turner 1968; Lewder *et al.* 1995; Jackson and James 1970; Mortimer 2007; Hatcher *et al.* 2009). Selective breeding for resistance to body strike has been known and practiced in industry for some time using indicators such as fleece rot, variation in fibre diameter, wool colour and the wax:suint ratio (Dunlop and Hayman 1958; Atkins and McGuirk 1979; James *et al.* 1989; Raadsma and Wilkinson 1990; and Raadsma *et al.* 1993; and reviewed by Norris *et al.* 2008). Selective breeding to reduce dags (Greeff and Karlsson 1998, 1999; Woolaston and Ward 1999), which is well recognised as a predisposing factor to breech strike (Morley *et al.* 1976; Watts and Marchant 1977), has also been the subject of investigation, but more in relation to internal parasites and to reduce the costs associated with removing dags, than for reducing flystrike *per se.*

At commencement of the breeding program described below, little was known about the effectiveness and commercial impact of breeding to reduce breech strike, especially over a range of environments. However, evidence since the commencement of the current study supports the potential for selective breeding for breech strike resistance (Mortimer et al. 2007; Edwards *et al.* 2009; Brown *et al.* 2010; Scholtz et al. 2010; Scobie *et al.* 2011; Greeff *et al.* 2014).

Concurrent to the study conducted by CSIRO at Armidale, an equivalent was maintained in the Mediterranean environment of southern Western Australia (Greeff *et al.* 2014). Using predominantly medium-wool Merinos it was determined that dags, urine stain, neck wrinkle and breech cover were the indirect selection criteria most useful for breeding for reduced breech strike in that environment.

4. PROJECT OBJECTIVES & SUCCESS IN ACHIEVING OBJECTIVES

- **Original objectives set in 2005**

a) Evaluate potential indirect selection criteria for breech strike

Achieved. A large set of wrinkle, wool cover and other breech-related traits were evaluated at several age stages. Breech wrinkle, dag and breech cover were determined to be the most suitable candidates as indirect selection criteria for breech strike.

b) Develop industry best practice guidelines for including breech strike resistance in Merino breeding programs

Achieved. Methodology for recording indirect selection criteria for breech strike have been developed and are incorporated into documents for industry, such as the Visual Sheep Scores, ParaBoss website, and Sheep Genetics Quality Assurance Manual.

c) Make preliminary estimates of heritability and correlations between breech and production traits – the tools to estimate genetic gain

Achieved. Heritability, phenotypic variance, and phenotypic and genetic correlations have been calculated for breech strike at weaner, yearling and adult age, as well as for the large set of potential breech strike indirect selection criteria. Phenotypic and genetic correlations between breech strike and production traits, and between the potential indirect selection criteria and production traits have also been estimated.

Objectives of current project (2012-2015)

a) Continued development of the Armidale breech strike genetics resource flock Resistant and Susceptible selection lines

Achieved. The Resistant and Susceptible selection lines have been maintained and remain genetically linked to industry flocks. The flock has continued to be fully pedigree recorded with single sire matings in 2012, 2013 and 2014, and maternal pedigree recorded at birth through twice-daily lambing rounds. The flock has continued to be phenotyped for a range of wrinkle, wool cover, and other breech traits (marking, post-weaning, yearling and adult ages); fleece traits;

reproduction; bodyweight (birth, weaning, post-weaning, yearling, and adult); and other disease traits (fleece rot and intestinal parasite resistance).

Phenotypic and genetic parameters for breech strike and potential indirect selection criteria for breech strike have been re-estimated utilizing the entire dataset (2005-2014 drop).

In 2015, with impending closure of the Project, a natural mating within selection lines was conducted. The 2015 progeny were just born at the close of this Project. It was originally not intended to record pedigree or any performance data on these animals at birth. However, for the purpose of a separate study on accuracy of prediction of parturition date from foetal age data collected at pregnancy scanning, the lambing was fully recorded. Lambs were tagged at birth, and maternal pedigree and other birth details recorded.

The entire flock, comprising the breeding flock (n=431 ewes and their new-born lambs), 2014 drop ewes (n=239) and rams (n=236), and sires (n=22) was transferred to the CSIRO Chiswick farm at close of this Project.

The flock management and recording program has provided a valuable resource for other activities and enables more robust genetic evaluation of the consequences of including breech strike resistance in Merino breeding programs.

b) Supply wool and tissue (skin) samples to UWA to assist in their aims to;

i) identify other factors influencing risk of flystrike (i.e. odour)

ii) develop tools for breeders to assist them to accelerate the rate of genetic improvement in resistance Australian sheep to breech strike.

Achieved. Wool and tissue samples from the Armidale flock have been sent to the WA team as requested. Initial requests did not come until late in the Project period.

September 2014. 2013 drop as yearlings, n=207 ewes and n=227 rams, collected pre-shearing

- Crutch wool sample
- Breech skin sample
- Accompanying data file (inc. pedigree, fixed effects, flystrike history, fleece traits, bodyweight)

June 2015. Breeding flock ewes, n=431; 2014 drop as yearlings, n=239 ewes and n=236 rams; sires, n=22, all collected pre-shearing

- Midside and crutch wool sample
- Accompanying data file ((inc. pedigree, fixed effects, flystrike history, fleece traits, bodyweight)

To date, some of the wool samples from the 2013 drop progeny have been tested by UWA in a ‘blowfly maze’ during 2015, and some of the skin samples were sent for DNA extraction for bacterial profiling in June 2015.

Johan Greeff (DAFWA) notified CSIRO in September 2015 that the skin samples from the Armidale 2013 drop progeny are not suitable for individual bacterial profiling. Hence, CSIRO has been asked to not proceed with skin sampling the 2014 drop progeny at this point as it may be necessary to re-sample the remaining 2013 drop progeny.

c) *Evaluate whether tail docking method, or docked-tail length affects breech strike risk in later life*

Achieved. The 2012 and 2013 drop progeny were involved in a tail-docking methods study. Lambs were tail-docked by four different methods; regular hot iron, te Pari Patesco hot iron, cold knife, and elastrator ring. Breech strike phenotypes were obtained from the 2012 drop males and females as weaners (2012-13 fly season) and yearlings (2013-14 fly season), and from females retained in the breeding flock in their first adult year (2014-15 fly season). The 2013 drop progeny have flystrike records as weaners (2013-14 fly season) and yearlings (2014-15 fly season).

Preliminary results were reported in TMS-03 and TMS-05 and extended in the section below. In summary, there is no consistent evidence for effects of tail-docking method on later-age breech strike. The breech strike rates among sheep tail-docked by the different methods ranked differently across years and sheep age classes, and in most cases were not statistically different. Docked tail length was measured at post-weaning and statistical analysis undertaken to determine any effect on later age breech strike rate of docked tail length. In this flock there was no significant effect of docked tail length on breech strike rate.

d) *Supply genomic material and phenotype data to a separate study of breech strike genomics (CSIRO and AWI)*

Achieved. In 2013-14 CSIRO conducted a Project on breech strike genomics (AWI WP550). The genetic and genomic material for that study came directly from the Armidale and Mt Barker Breech strike genetics flocks. While that collaborative genomics project is complete, CSIRO continues to investigate SNP associated with breech strike resistance/susceptibility.

e) *Supply pedigree and phenotype data to NSW DPI for a separate study of post-weaner fleece traits.*

Achieved. The 2012 and 2013 drop progeny in the Armidale breech strike genetics flock were used in a study of genetic parameters for post-weaner fleece traits that was conducted by NSW DPI. Instead of the regular yearling (September) then first adult (July) shearing, animals from those two progeny groups were shorn at the following times:

- Post-weaner, late-April, 7.5months of age, 7.5 months wool growth
- Hogget, mid-December, 15 months of age, 7.5 months wool growth
- First adult, mid-July, 21.5 months of age, 7.5 months wool growth

Midside wool samples were collected prior to shearing. Style component traits including handle, greasy wool colour, character, dust penetration, density and fleece rot were assessed at that time. The samples were measured for mean fibre diameter, variation in fibre diameter, washing yield, and mean fibre curvature. Greasy fleece weight was recorded at shearing and clean fleece weight derived using greasy fleece weight and the yield measurement. Unfortunately, due to the shortened wool growing period, these sheep never grew sufficient wool during that experimental period to enable an objective measure of staple length and strength. All necessary data, including pedigree, fixed effects, bodyweight, and fleece traits (assessed and measured) have been sent to NSW DPI, Orange, NSW for a combined analysis.

f) ***Through use of industry link sires and supply of pedigree and high-quality phenotype data to Sheep Genetics, enhance industry uptake of breeding sheep for breech strike resistance.***

Part Achieved. All relevant pedigree, and phenotype data from the Armidale breech strike genetics flock has been submitted to Sheep Genetics and is included in routine data runs. However, I am not privy to metrics around uptake of Sheep Genetics or the use of breech trait ASBVs (eBRWR, eBCOV and lDAG) by industry.

Link sires used since the formation of the Resistant and Susceptible lines in 2011 from the earlier flock structure are listed in Table 1.

Table 1. External sires used in the Armidale breech strike genetics flock since 2011 for genetic linkage to industry.

Year	Source	Sire ID	Progeny/flocks	Usage
2014	Yalgoo	501552-2007-070441	1214/13	MSS, SCRC, DNA
2014	Petali	601279-2010-100549	490/8	MSS, SCRC, DNA
2013	Petali	601279-2009-090229	407/7	SCRC, DNA
2012	T13	504997-2005-0A3156	300/6	MSS
2011	Karori	504773-2004-040562	278/8	SCRC, DNA
2011	Alfoxton Poll	601333-2006-060026	343/5	
2011	Nerstane	503298-2001-010078	1186/23	MSS, SCRC, DNA

MSS = Merino Superior Sires, SCRC = Sheep Industries CRC Information Nucleus, DNA = genomic information

Note: The following Sections 6 and 7 relate specifically to the revised genetic parameter estimation and the study conducted on tail docking methods. Other components of this Project did not involve an experiment as such, but maintenance of a resource for other studies and supply of data and biological samples to other organisations

5. GENETIC PARAMETER ESTIMATION FOR BREECH STRIKE AND POTENTIAL INDIRECT SELECTION CRITERIA FOR BREECH STRIKE

5.1 Methodology

The CSIRO breech strike genetic resource flock was established in 2005 and was maintained for 10 years. The flock consisted of predominantly fine wool Merinos and the New England environment is summer-dominant rainfall. A similar flock was maintained over the same period at Mt Barker in Western Australia, comprising predominantly medium wool Merinos in a Mediterranean environment.

Animals reported upon here (n=4656) were born between 2005 and 2014 inclusive and are the progeny of 72 sires and 1634 dams. Sire progeny group sizes ranged from 17 to 139, with at least 1 across-year link sire used annually. Five hundred and twenty progeny in the first year (2005) have unknown pedigree as they were sourced from industry flocks as described below.

From 2005 to 2009 inclusive, the flock comprised 3 selection lines; *Intense Selection (Intense)* – active selection on breech traits of both sires and dams; *Commercial Improvement* (Commercial) – unselected ewes and active selection on breech traits on the sire side only; and *Unselected Control* (Control) – random selection. No mating was conducted in 2010. In 2011 the flock structure was changed to just two selection lines, being Resistant – selection of sires and dams against breech strike; and Susceptible – selection of sires and dams for breech strike. At that time, animals comprising the three original selection lines were either re-allocated to one of the two new selection lines or were culled. The flock structure remained as those two selection lines for the remained of the experimental period. The change to the flock structure and selection procedure is described further in the next section. The flock design is demonstrated in Figure 1.

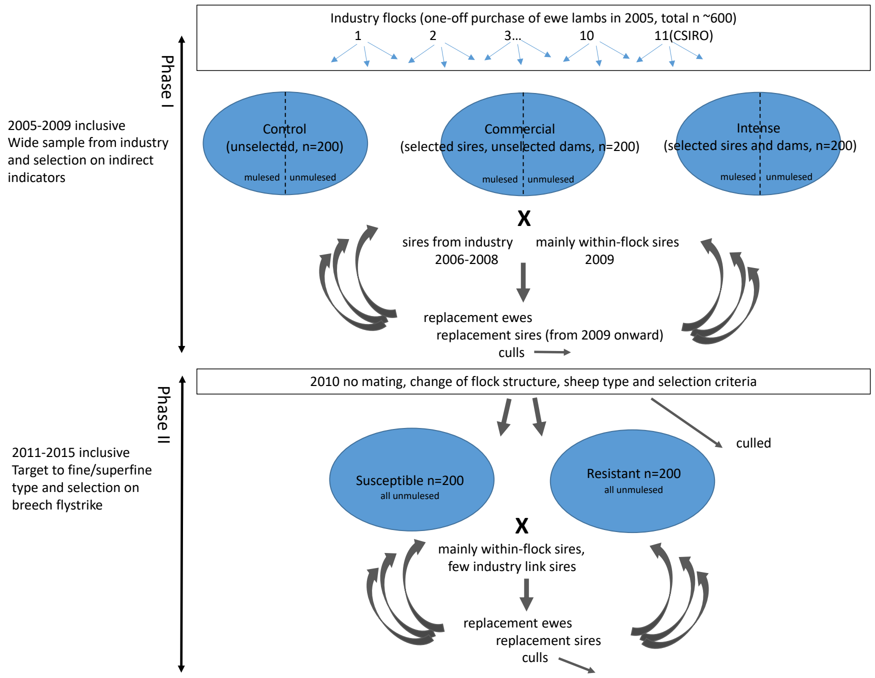

Figure 1. Schematic of design of Armidale breech strike genetic resource flock

During the period 2005-2009, half the sheep in each line were mulesed and the other half remained unmulesed. After 2009 all sheep remained unmulesed. Throughout the experimental period, the sheep were managed under natural flystrike challenge conditions in the absence of preventative chemical treatment for flystrike. Only animals that became fly struck were treated and with a short-acting insecticide so as not to preclude re-strike.

After the initial set-up period, the selection lines were managed to be self-replacing apart from the strategic use of external sires for genetic linkage to industry via Sheep Genetics (Sheep Genetics 2006a). All ram lambs born into the flock were kept entire. Replacement ewes (usually approximately 65% of the year group), and potential sires and reserves (usually 20-30 annually, or approximately 5-10% of the year group), were selected at approximately 15 months of age, to be first mated at approximately 18 months of age and have first progeny at two years of age. Culling of ewes in the breeding flock was conducted across ages, but with a degree of preference for retention of younger ewes. A small number of ewes remained in the flock for up to eight years. Most sires were only used once, apart from those chosen as across-year genetic links.

5.1.1 Breeding flock establishment and annual selections

Founder adult ewes. The foundation flock consisted of 600 adult ewes sourced from a commercially run CSIRO Resource Flock, and approximately 600 ewe lambs purchased from 10 industry flocks. The initial 600 adult ewes were selected from a larger flock of 1200 mixed age CSIRO resource flock ewes, maintained at the CSIRO property 'Chiswick', Armidale NSW. Of those ewes, 400 were selected at random for the Commercial and Control lines, then 200 ewes were selected from the remaining 800 for low phenotypic neck and body wrinkle score for the Intense selection line. These ewes had previously been mulesed, so no selection on breech wrinkle phenotype was possible.

Ewe lambs from industry. The ewe lambs, 2005 drop, 60 purchased from each of 10 industry flocks, were from the commercial tier of registered Australian Merino or Poll Merino studs in NSW and VIC and represented Ultrafine/Superfine (US) and Fine/Fine Medium (FFM) sheep/wool types according to *Sheep Genetics* classifications (sheep Genetics 2006b). Ewe lambs were obtained from the following flocks; Goyarra Poll, Western VIC; Hazeldean, Monaro NSW; Auchen Dhu Park, Cressbrook, Gostwyck, Miramoona, Quambaloo Poll, Ruby Hills, Whyworry Park, and Yalgoo, all New England, NSW.

Ewe lambs were selected on phenotype at lamb-marking by CSIRO staff using assessments of body wrinkle, breech wrinkle, and inguinal bare area (all scored 1-5). At that time, the lambs were tagged according to intended selection line and half of each group assigned for mulesing or not, at the time of tail docking. Lamb-marking was conducted at average age of approximately 6 weeks. The lambs remained on their property of origin until shortly after weaning at approximately 12 weeks of age when they were delivered to the CSIRO property, Chiswick, Armidale, NSW. These lambs were of unknown pedigree and weaning weight was not recorded.

At each property, the ewe lambs chosen were from within a single mob (birth group) which ranged in size between properties from approximately 120 to 800 ewe lambs. There was no prior selection of replacements by the owners. Hence, the percentage of ewe lambs selected ranged from 7.5% to 50% of their cohort, with 30% or less selected from 8 of the 10 flocks. Ewe lambs for the Commercial and Control lines were chosen at random first, then plainer and barer lambs were chosen for the Intense line. For the Intense line the wrinkle and wool cover thresholds applied to make the selections varied between properties depending upon the mean and range in wrinkle and wool cover observed.

Breeding flock 2005-2009. CSIRO Resource Flock ewes were used as the initial breeding stock in 2005 and 2006 as an interim measure to generate progeny until the ewe lambs purchased from industry reached breeding age. Prior to establishment of the Breech Strike Genetic Resource Flock in 2005, those CSIRO Resource Flock ewes had been mated in a random bred syndicate of sires in April 2005 and lambed over a 6-week period from early September 2005. The ewe progeny from that mating were used as a pool to replace lambs from the industry flocks that were selected, but not received, from the industry suppliers. The 600 CSIRO Resource Flock ewes were used as the breeding flock again in 2006 but, were mated to selected sires in that year. From 2007 onward the Breech Strike Genetic Resource Flock comprised 532 ewes that were purchased as lambs in 2005, approximately seventy 2005 drop ewes from the CSIRO Resource Flock, and ewe lambs subsequently bred from them. Up to and including 2009, an annual selection of incoming replacement ewes was made from those born two years prior. In all lines there was preferential culling for any congenital defects, wool pigmentation, conformation defects, and ewes that failed to become pregnant for two consecutive years. Otherwise, for the Commercial and Control line, ewes were culled and replaced at random, balanced for property-of-origin and/or sire, as well as age and mulesing group. In the Intense line, ewes were selected or culled on breech phenotype, specifically breech cover, crutch cover, breech wrinkle and body wrinkle (approximately in that order of importance), and balanced as far as possible with the other two lines for ewe age. Approximately 65-70% of available young ewes each year became replacements in the breeding flock. Although no mating was conducted in 2010, the recording program for existing animals continued during that year.

Breeding flock 2011 onward. In 2011 several changes to the flock structure were made. The aims were to change the selection criteria from breech strike indicators to breech strike itself, and to remove sheep that were clearly not suited to the summer rainfall environment of Armidale. The following selection process was conducted in four stages following a preliminary cull for any congenital, pigmentation, or conformation faults, and repeated failed pregnancy. Firstly, a cull based on wool type and fleece traits was conducted to constrain the flock to a superfine/fine wool type. The predominant selection criterion for this stage of culling was yearling fibre diameter Australian Sheep Breeding Values (yFD ASBV), with the broadest one-third of ewes culled. Secondly, any ewe that had been body struck at any time in the past was culled, along with any ewe that had yearling dermatitis or fleece rot score greater than one. Thirdly, all ewes among those remaining that had been breech fly struck were retained for the Susceptible line. Finally, ewes were classified as Resistant or Susceptible predominantly using phenotypic breech wrinkle records up to yearling age, and early breech wrinkle (eBRWR) ASBV. Variation in breech cover and dag score was low and so were minor considerations in the selection process. For the overwhelmingly large majority of ewes, those from the Intense line were allocated to the Resistant line, and those from the Control line were allocated to the Susceptible. Ewes from the Commercial line, which was dissolved, moved either to the Resistant or to the Susceptible line. Younger ewes were retained preferentially because the 2005 drop had no pedigree and fewer phenotypes. 32% of 2005 drop ewes, 39% of 2006 drop ewes, and 50% each of 2007-2009 drop ewes were retained. The new Resistant and Susceptible lines were approximately balanced for ewe age and mulesed/not.

The decision to cull ewes with body strike, severe fleece rot or dermatitis was taken because the project focus was breech strike, rather than other forms of strike or associated diseases. This may have had unintentional implications for future research on odours associated with breech strike. However, even in young sheep (the most susceptible to body strike), body strike never exceeded 3% in any one year, so exclusion of those animals is unlikely to have had major impact on breech strike (or characters associated with it) in the remaining population

From 2012 onward, the annual selection process within lines resembled that of the early years. That is, a preliminary cull in both lines for congenital, wool pigmentation or conformation faults, and repeatedly non-pregnant. In the Resistant line, any ewe that was breech fly struck was culled, and replacements were then selected sequentially on a) low within-flock weaner breech strike estimated breeding values (wBRSTR EBV); and then b) low ASBVs for eBRWR, early breech cover (eBCOV), and late dag (lDAG). In the Susceptible line, any ewe that was breech struck was preferentially retained, and then selection was based on high wBRSTR EBV, followed by high ASBV's for eBRWR, eBCOV, and lDAG. If there was any scope for further culling on production traits, this was focussed on ASBV's for yearling bodyweight (yWT), yearling clean fleece weight (yCFW), and yFD.

The 2014 drop progeny were the last to be phenotyped for breech strike and breech strike indicators.

5.1.2 Sire selection and usage.

Four or five sires were used in each line every year and each was mated to 40 or 50 ewes depending on the number of sires used in that year. The majority of mating was conducted by artificial insemination and is further described below. Every year the sire team included at least one across-year, and one across-flock (with Mt Barker, WA) link sire. In 2006 to 2008 inclusive, all sires were drawn from industry. From 2009 onward, only the link sires were from industry with all other sires selected from within the flock. Up to and including 2009, the sires used represented all three of the Sheep Genetics sheep/wool types (US, FFM and Medium/Strong (MS)). However, for logistical and economic reasons, there was a degree of imbalance of sire type usage across selection lines in that no MS wool sires were used in the Control line. The large majority of sires from industry were performance recorded in Sheep Genetics for production traits, many with progeny recorded in multiple flocks. Sires used over the life of the study were drawn from the following studs; Alfoxton Poll; Belka Valley; Bellaine; Calcookara; Centre Plus Poll; Centre Plus WA; Cressbrook; Karori; Miramoona; Nerstane; North Ashrose Poll; Quambaloo Poll; Petali; Roseville Park; Ruby Hills; Severn Park; Stockman Poll; Toland Poll; T13; Wallaloo Park; and Yalgoo.

The wide range in sheep and wool types arising from the original selection strategy prompted the 2011 change in flock design described above. From 2011, all industry sires used represented US or FFM wool types only.

In the first three years of the breeding program, the (external) sires were selected predominantly on own phenotype wrinkle and breech traits as there was little if any own genetic or progeny information available for those traits at that time. Sires for the Intense and Commercial lines were selected for low breech cover and breech wrinkle, and without conformation faults. Selection thresholds for the breech traits varied across years and was dependent upon the potential sires available in any particular year. Fleece and production characteristics were only considered if potential sires were otherwise similar. Sires with fleece and/or production characteristics regarded to be more suited to the local environment were preferred. Sires for the Control line were chosen simply to be similar in production traits to those used in the other lines and without conformation faults. Many of the Control line sires were from the CSIRO T13 stud, and collectively they had diverse ancestry. Sires used in 2009, which were drawn from within the flock were selected using within-flock EBV's for the breech strike indicators, then ASBV's for production traits. From 2011 onward, within-flock sires were selected primarily on wBRSTR EBV, then ASBV's for eBRWR, eBCOV, and production traits. The process for choosing sires from within the flock was short-listing within sire progeny groups using the above listed performance records, and then a sire and reserve was selected from each progeny group on conformation and overall suitability as a sire. Link sires from 2011 onwards were chosen from within the Sheep Genetics US or FFM wool type using ASBVs for eBRWR, eBCOV, and lDAG. Link sires with progeny records from more than one flock were preferred. In the life of the Project, only one sire was used in more than one line – in 2006 that sire was used in the Control line, and following progeny testing, was used again in 2009 in the Commercial line.

5.1.3 Genetic groups.

When this resource flock was set up a wide range in sheep and wool types was used with the intention of sampling widely to reflect the variation exhibited in the Australian Merino population. The 2005 drop progeny purchased from industry were all without pedigree, but their source flocks were classified approximately equally as Ultrafine/Superfine (US) and Fine/Fine Medium (FFM), according to Sheep Genetics sheep/wool types. Both types were also equally represented in all three selection lines. These genetic groups were included in the pedigree. All progeny born into the flock from 2006 onward were fully pedigreed. The large majority of industry sires used were also of US or FFM type, but in 2006 to 2008 inclusive at least one Medium/Strong (MS) wool sire was used in either the Commercial or Intense selection line.

Mating and lambing. Dams were assigned to sires for mating within selection lines and balanced for dam property-of-origin (where applicable), age, mulesing group, and sire-of-the-dam (where known). The matings in 2006, 2007 and 2008 were conducted exclusively by intra-uterine artificial insemination (AI) because the majority of sires used were drawn from industry. In 2009 most of the sires used were from within the flock and were initially mated by AI, and then the sires were natural back-up mated with the same ewes to which they were AI'ed. In that year, ewes that were AI'ed to the industry link sire were assigned (balanced for age and origin) to the other sires in that selection line for the back-up mating. Back-up matings were in single-sire groups, commenced 14 days after AI, and ran for 21 days. From 2011 to 2014 inclusive, the mating procedure was similar to 2009. That is, mated initially by AI, followed by a back-up mating, with the same process for assigning ewes AI'ed to the external sires for back-up mating by other sires in the same selection line.

Ewes were ultrasound pregnancy scanned at approximately day 60 after AI to determine litter size, and from 2009 onward, also for identification of ewes pregnant from AI or back-up mating. Approximately 1 week prior to lambing, ewes were assigned to lambing groups according to AI day/back-up and sire group. Lambing groups were randomly allocated to lambing plots, of which there were 36. Lambing rounds were conducted twice daily for tagging, identification of maternal pedigree, and recording of birth details including birth weight, sex, birth type, wrinkle and breech scores. Generally, ewes and lambs were drifted out of the plots into a neighbouring paddock approximately 1 week after all ewes in the plot had lambed.

5.1.4 Annual production calendar

Figure 2. indicates the annual production calendar for the flock, along with long term average rainfall and temperatures. The flystrike season in this environment is largely governed by the absence of frost, but flystrike risk is also associated with rainfall, temperature, humidity and wind speed.

In contrast to the WA flock where crutching time varied during different phases of the study, at Armidale crutching time did not change for the duration of the study period. Crutching of all sheep classes was conducted in early autumn, toward the end of the flystrike season, which is standard practice for the region. Ewes were shorn in mid-winter to lamb off-shears in early spring. Young sheep were first shorn as yearlings in August or September. This meant that yearlings experienced the shortest flystrike exposure period when not under the protective influence of shearing or crutching.

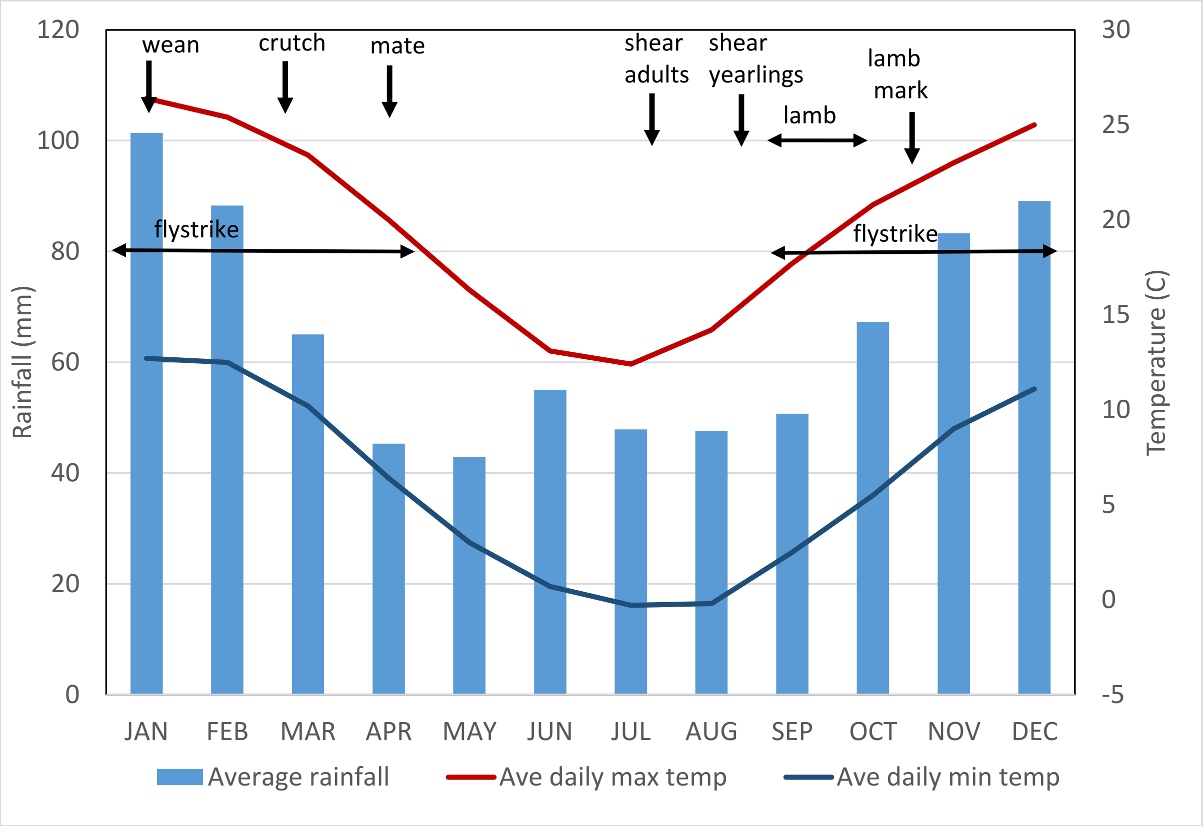

Figure 2. Long term average rainfall and monthly minimum and maximum temperatures, with major calendar events in the annual production cycle in relation to the usual flystrike season for sheep at Armidale.

5.1.5 Conduct of mulesing

Up to and including 2009, half of the lambs each year and within each selection line were mulesed at lamb marking. Assignment of lambs to be mulesed or not was balanced for selection line, sire, age of dam, birth-rearing type, sex and age. After 2009 no mulesing was conducted on this flock. The mules conducted on the sheep in this experiment was regarded to be typical of that conducted on sheep in the local New England region and is considered to be 'conservative' in comparison to that performed in some other regions of Australia. The mules conducted was a single skin strip from each side of the breech plus removal of a skin strip from each side of the tail. The mulesing was conducted by different operators in different years – in 2005 mulesing was conducted by 11 different operators as the sheep were mulesed before CSIRO took delivery. In 2006 and 2008 the sheep were mulesed by operator '1' and in 2007 and 2009 by operator '2'. Engagement of different mulesing operators was not a deliberate part of the experimental design, but simply a function of availability. All operators were accredited under the National Mulesing Accreditation Program (NMAP).

5.1.6 Wrinkle, wool cover and other breech traits

Wrinkle, wool cover, tail characteristics, and other traits potentially associated with breech strike, were assessed or measured on both males and females at birth (b, during lambing rounds), lamb-marking (m, at time of tail-docking/mulesing, approximately 6 weeks of age), post-weaning (p, approximately 6 months of age), and yearling age(y, off-shears at approximately 11 months). After that, ewes were recorded as hoggets (pre-mating at approximately 18 months), then annually as adults for as long as they remained in the breeding flock. Usually certain measurements were made on adult ewes pre-mating and pre-lambing.

Table 2. details the key traits examined throughout this study: the recording methods and age at which they were recorded. In some cases, adjustments were made to the times at which certain traits were recorded. For example, after several years of data were collected, it became evident that neck and body wrinkle scoring of woolly sheep (as opposed to off shears) was of dubious value, as was wrinkle scoring of heavily pregnant ewes. Turning heavily pregnant ewes over in a sheep handler to assess wool cover traits was deemed to be to the detriment to the animals and hence also discontinued. Face cover, recorded on yearlings, and annually on retained adult ewes prior to shearing, is reported with wrinkle and other wool cover traits.

Docked tail length was a measurement introduced for a specific evaluation of the effect of this trait on lifetime breech strike. Cannon bone length was used in the early years as a proxy for body weight at lamb-marking when it was impractical to body weigh.

Urine stain scoring was introduced as a new trait in 2007, and only on females. Expression of dag in this flock was usually low. Dag scoring was only routinely conducted at post-weaning which was usually the time period when dag was greatest. Occasionally dag was also scored opportunistically following an outbreak of scouring in older sheep, but results relating to those older-age dag scores are not reported here.

The 2012 and 2013 drop progeny were involved in a separate study which involved shearing at post-weaning and hogget ages rather than as yearlings. This inevitably disrupted the usual breech trait recording program normally conducted at yearling age. For example, the 2012 drop progeny were still recorded for breech traits as yearlings even though they had 5 months wool growth when they would normally be off shears.

Various other traits were also tried and tested at during the experimental period but were discontinued following judgements around their usefulness. Such traits included points (leg) cover; diagonal dimensions of breech bare area; total and bare width of tail at the butt; length of bare area on ventral tail; assessed shape of breech bare area; and classification of breech wrinkle types. These traits are not detailed here.

For all assessed wrinkle, and wool cover traits, the assessor was recorded and where the cohort was assessed by more than one operator, operator was tested as a fixed effect and included in the statistical model if significant.

Table 2. Summary of wrinkle, breech and tail trait measurements.

Trait	Description	Method	Ages measured				
			Birth	Mark	Post-wean	Year	Adult [1]
NWR	Neck skin wrinkle	1 – 5 (1 = least)[2]	✓	✓	✓	✓	✓
BWR	Body skin wrinkle	1 – 5 (1 = least)[2]	✓	✓	✓	✓	✓
BRWR	Breech skin wrinkle	1 – 5 (1 = least)[2]	✓	✓	✓	✓	✓
BCOV	Breech wool cover	1 – 5 (1 = least)[2]	✓	✓	✓	✓	✓
CCOV	Crutch wool cover	1 – 5 (1 = least)[2]	✓	✓	✓	✓	✓
FACE	Face wool cover	1 – 5 (1 = least)[2]					✓
BW	Breech bare width, lateral dimension (width) of perineal bare area	Ruler, to 5mm measured at anus		✓	✓	✓	✓
BD	Breech bare depth, dorso-ventral dimension (depth) of perineal bare area [4]	Ruler, to 5mm measured from anus to ventral edge of breech bare area		✓	✓	✓	✓
TL	Tail length	Ruler, to 5mm		✓			
DTL	Docked tail length	Ruler, to 5mm			✓		
DAG	Dag score	1 – 5 (1 = least)[2]			✓		
URINE	Urine stain score	1 – 5 (1 = least)[2]			✓		
CBL	Cannon bone length (point of hock to fetlock)	Ruler, to 5mm		✓			
[1] Adult measures made annually while ever animals remained in the breeding flock. Wool cover traits were scored/measured pre-mating while wrinkles were scored off-shears. [2] Traits assessed based on Visual sheep Scores (2013) or earlier editions							

5.1.7 Flystrike recording

In the Armidale environment incidence of flystrike is largely governed by the absence of frost, so the flystrike 'season' runs throughout the spring, summer and autumn from approximately October to April inclusive. During this period the flystrike monitoring protocol for the flock was checking 3 times per week. This was done either by holding the mob in a corner of the paddock or, when flystrikes were prevalent, mustering to the yards to check every individual. This procedure was found to be successful for identifying and treating flystrikes early such that the welfare impact on the animals was minimised.

There was provision for preventative chemical treatment of the flock in the event of a 'fly wave' but this was not enacted in any year of the experimental period. Hence, no whole-flock preventative flystrike treatment was administered except for application of short-acting (7-10 days) Spinosad (Extinosad™) at lamb marking. Lambs were treated on the tailing and mulesing wounds, and the ewes were treated on the breech and udder. The latter was undertaken in order that the sheep did not have to be mustered in the week following mulesing/tail-docking to facilitate wound healing. Flystrikes were treated by hand-clipping or machine-clipping the flystrike site and surrounding wool, and treatment with Spinosad (Extinosad™). This short-acting insecticide was used so as not to preclude re-strike.

Data recorded at the time of identification and treatment of flystrikes included; paddock/mob, animal identity, date, site (breech or other), size of flystrike site (approximate, to nearest 5 cm diameter), dag score, and urine stain score (females only).

The flystrike traits used here were count of strikes over the season (approximately October to April). Weaner breech strike (wBRSTR) was that occurring in the animal's first flystrike season (i.e. commencing in the spring in the year in which they were born); yearling breech strike (yBRSTR) was that occurring in the animal's second flystrike season; and combined adult breech strike (aBRSTR) was the sum of breech strikes occurring in each consecutive flystrike season for which the animal was retained in the flock. Both males and females have weaner and yearling flystrike records. Only females retained in the breeding flock have adult flystrike records. The 2005 drop progeny obtained from industry have no weaner age flystrike records because most were treated with either dicyclanil or cyromazine at lamb-marking prior to delivery to the CSIRO property.

Breech strike (BRSTR) was flystrike occurring on either the breech or tail. The two were grouped together because the large majority (92%) of breech strikes were deemed to have started on the breech (i.e. below the tail). Body strike (BSTR) was that occurring on the neck, shoulders, back and hips. Poll strikes among rams were recorded, but are not reported or considered in any detail in this study because in most years the rams were provided preventative poll strike treatment (dicyclanil, Clik®) in early summer to avoid possible infertility issues associated with poll strikes.

In the 2009-10 and 2010-11 flystrike seasons, the ewe cull was performed late and all ewes retained until toward the end of the flystrike season. Hence, there were more adult flystrike records in those years than the other years when ewes were culled earlier.

5.1.8 Fleece traits

Fleece traits were recorded on yearlings and adult ewes for every year that they remained in the breeding flock. An exception was the 2012 and 2013 drop progeny which were involved in another study which required they be shorn at post-weaning and hogget ages rather than yearling. Yearling fleece traits for the 2012 and 2013 drop progeny are included in the dataset but are adjusted values based on the post-weaning and hogget records. For those two progeny groups, yearling greasy and clean fleece weight was the sum of post-weaning and hogget fleece weights adjusted to 347 days (mean yearling age of all other drops). All other yearling fleece traits for those two progeny groups were taken to be the mean of the post-weaning and hogget records. Staple length and strength were not recorded in those years because the sheep grew insufficient wool in those periods to obtain those trait measurements. Only the first adult (a2, two-year old) fleece data is reported in any detail here because there were insufficient older age records due to culling across ages, and confounding of repeated reproduction events compromised genetic parameter estimation of older adult traits. Specifically, at the first adult shearing the sheep were only 21 months of age with 10 months wool growth

Midside wool samples were collected 1-2 weeks prior to shearing. The fleece traits recorded were washing yield (YLD, %), mean fibre diameter (MFD, µm), standard deviation fibre diameter (SDFD, µm), coefficient variation fibre diameter (CVFD, %), and mean fibre curvature (MFC, º/mm). Greasy fleece weight was recorded at shearing and clean fleece weight (CFW, kg) was derived from GFW and YLD. In addition, a suite of assessed fleece style traits were recorded at wool sampling. Of those style traits, only greasy wool colour (COL), character (CHAR), and fleece rot (FLROT) are reported upon here. All were based on the method described in Visual Sheep Scores (2008).

5.1.9 Reproduction traits

Matings were conducted largely by artificial insemination followed by natural back-up mating. In 2005 the mating of CSIRO resource flock ewes was natural and to random-bred sires, and the 2005 drop ewe lambs purchased from industry all arose from natural matings. In 2006 to 2008 inclusive, mating was entirely by AI to industry sires. In 2009 to 2014 inclusive, mating was initially by AI with a back-up natural mating using predominantly sires bred within-flock and just a few industry sires for genetic linkage. A natural mating was conducted in 2015. With the exception of 2005 and 2015, all natural matings were in single sire groups. Pregnancy scanning for litter size was conducted annually and daily lambing rounds conducted. Reproduction traits recorded were fertility (FERT, pregnant/not from pregnancy scan), scanned litter size (SCAN), number of lambs born (NLB, from lambing rounds) and number of lambs weaned (NLW), lambs present at weaning.

5.1.10 Other traits

Bodyweight was recorded on all animals at birth, weaning, post-weaning, and yearling ages, as well as pre-mating and off-shears (mid-late pregnancy) for breeding ewes.

Worm egg count (WEC, epg) was recorded following natural challenge at post-weaning, usually in March or April, but depending upon seasonal conditions.

5.1.11 Statistical analyses

Summary statistics for the following trait groups are reported here: flystrike; wrinkle, wool cover, and breech related traits (up to and including yearling age); yearling fleece traits; two-year old (a2) adult fleece traits; bodyweight (up to and including yearling age); and worm resistance. Determination of statistical normality was based on degree of skewness and kurtosis, and data transformations tested and applied as necessary.

Statistical analyses were conducted using ASReml (Gilmour et al. 2008) and the specific model used varied depending upon the objective of particular analyses. Generally, fixed effects models were initially tested to identify significant fixed effects. Mixed animal models were used for the genetic parameter estimation. Maternal effects on potential indirect selection criteria traits were tested but were usually non-significant so excluded from further analyses. Phenotypic and genetic correlations were estimated from 5-trait multivariate models with the first 3 traits being BCOV, CCOV and BRWR (being the key selection criteria in Phase I), with pair-wise combinations of all other traits of interest.

A set of fixed effects were routinely tested where appropriate and included where significant. These were selection line, mulesed/not, sex, birth-rearing type, age of dam, and contemporary group (combined birth year and management group). Age and/or bodyweight were included as linear covariates where significant.

Breech strike is an important disease in all sheep classes, but the statistical analyses are concentrated on the weaner age trait because the majority of flystrike data were on the young animals. Older age flystrike data is examined, but to a lesser degree than the weaner age trait. Phenotypic variance and heritability are estimated separately for yBRSTR and aBRSTR, but for estimation of phenotypic and genetic correlations with yearling breech strike indicator traits, and with two-year old adult fleece traits, breech strike data from female yearlings and adult ewes were combined (y-aBRSTR). The A2 production data is important for better estimates lifetime productivity.

In an attempt to quantify the relative contribution of the various indicator traits to breech strike resistance, a mixed model was fitted to partition variance. Initially a base (null) model was fitted, followed by the fixed effects of selection line, mulesing, sex, birth-rearing type, age of dam, management group (which incorporates birth year), and body weight (fitted as a linear covariate). Animal was then fitted as the first random effect, followed sequentially by the five key indicator traits, being yBRWR, yBCOV, yCCOV, pDAG and pURINE. Contribution of each component was calculated by subtraction and expressed as a percentage of phenotypic variance. This exercise was conducted for both wBRSTR and y-aBRSTR.

5.2 Results and Discussion

Aspects of the experimental design of this study were changed while it was in progress. The original intention in the establishment of this flock was to sample widely to evaluate the variation available in the Australian Merino population, particularly in breech cover. In Phase I, there were three selection lines with a wide range of Merino types represented; the selection criteria were the indirect selection criteria breech cover, crutch cover and breech wrinkle; and half the sheep in each line were mulesed. In 2010 the design for Phase II was modified to two selection lines restricted to fine wool type; the primary selection criterion was breech strike itself; and all of the sheep were unmulesed. These decisions were not taken lightly and did inevitably impact on the complexity of the study, the precision of results, and the clarity of conclusions to be drawn. Nevertheless, the author regards that the data quality obtained is sufficient to address the project objectives.

It should be remembered that genetic parameters estimated are most relevant to the population from which they were derived, but there is an expectation that to a degree, they will be applicable in other similar populations. The foundation flock for this study was built from many industry flocks. While this provides commercial relevance in terms of a representative and industry-current genetic resource, this is not usual method of building industry flocks, and the founder animals came without the valuable quantitative genetics background information of known pedigree and phenotypes. Hence, the flock developed was a compromise between industry relevance and research needs.

Throughout the study, a core set of traits were recorded repeatedly up to yearling age to generate the information needed to develop the methods that would form the industry guidelines for incorporating genetic improvement in breech strike resistance into Merino breeding programs. That is, the intention was to identify which traits were of the most value as breech strike indicators; at what age was it best to measure them; and how to record them in a manner that could be readily incorporated into the existing Merino breeding calendar of events and measurement programs. Most of the traits potentially of commercial use were assessed on a five-point scale. Additional traits, such as the measured bare width and depth of breech bare area were included as a means of validation of the assessed breech cover score.

5.2.1 Summary statistics

Flystrike. Figure 3 shows the average percentage of sheep breech struck over the 10 years of the study period for the three main sheep classes (weaners, yearling ewes and adult ewes) by calendar month. December and January were the months of greatest flystrike risk. Although the weather was still highly conducive to breech strike in February and March, crutching was conducted in that period (the exact timing changing from year to year), and likely reduced the overall strike rates during those months. Figure 4 shows breech strike rates by year, also for the three main sheep classes, with rainfall for the fly season (October to April) for each year. The first seven years of the study period had higher than long term average (LTA) rainfall for the fly season, and the last three years were lower than LTA.

Initially it appears that rainfall has little relationship to the breech strike rate in any particular year. However, remembering that in Phase I half the sheep were mulesed while in Phase II all the sheep were unmulesed, effectively, had all the sheep in Phase I been unmulesed, the breech strike rate in that period would likely be double that observed. Nevertheless, it is clear that environmental effects other than rainfall affect breech strike risk.

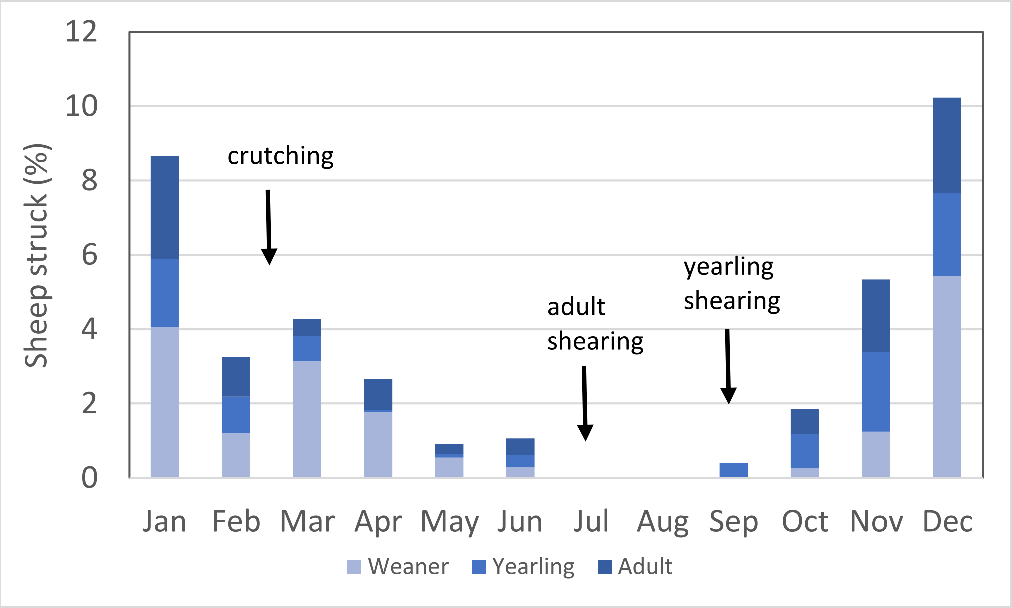

Figure 3. Percentage of flock struck by sheep class (mixed sex weaners; combined ewe and ram hoggets; and breeding ewes) and calendar month, averaged over the 10-year study period (2005 to 2015)

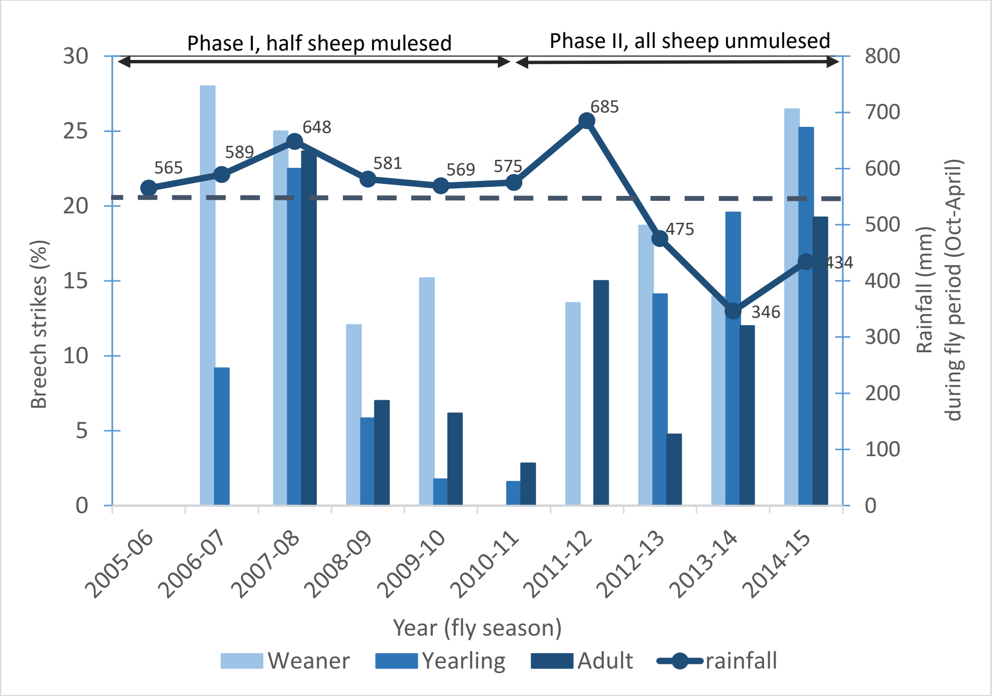

Figure 4. Mean arithmetic breech strike rate (%) for weaners, female yearlings, and breeding ewes in each year of study period, with mean rainfall for the fly season (October to April, inclusive). Long term average (LTA) annual rainfall for the region is 785mm, and LTA rainfall for the usual fly season (dotted line) was 540mm. [Note, no flystrike records are reported for 2005-06 because the weaner ewes purchased from industry were pre-treated with systemic preventative chemicals. There were no weaners (most susceptible class of sheep) in 2010-11, and no yearlings in 2011-12.]

Table 3 shows summary statistics for weaner and yearling, body and breech strike, and also adult flystrike data by age (in years). Averaged over all years of the study, wBRSTR was 18.1% and yBRSTR was 7.6%. The weighted average aBRSTR for ewes aged 2 to 7 years, was 9.9%. Table 4 summarises breech strike rate by calendar years (effectively flystrike season). Body strike never exceeded 3% in any sheep class and is therefore not considered further here.

Several data transformations for flystrike were tested (square-root, cube-root, and logarithm). Natural logarithm provided the closest estimate of normality and was applied henceforth and breech strike was analysed as a quantitative trait.

Table 3. Summary statistics for breech strike (BRSTR) traits throughout the experimental period. The flystrike traits are recorded as the proportion of animals in the flock struck during the flystrike 'season' (approximately October to April inclusive).

							N									
	Mean	**Sd**	**Min**	**Max**	**Skew**	**Kurt**	**Total**	**2005**	**2006**	**2007**	**2008**	**2009**	**2011**	**2012**	**2013**	**2014**
wBRSTR	0.181	0.482	0	6	3.54	18.81	3394	172	408	241	342	510	337	466	442	476
yBRSTR	0.076	0.307	0	3	4.58	24.24	3311	623	385	231	336	497	341	460	438	0
a2BRSTR	0.172	0.473	0	3	3.07	10.06	1427	605	148	101	163	110	129	171	0	0
a3BRSTR	0.094	0.344	0	3	4.36	23.01	976	474	145	51	80	110	117	0	0	0
a4BRSTR	0.049	0.274	0	3	7.00	58.34	851	474	143	51	79	104	0	0	0	0
a5BRSTR	0.041	0.231	0	3	6.86	58.39	730	474	53	48	74	81	0	0	0	0
a6BRSTR	0.098	0.369	0	3	4.47	23.18	254	116	52	44	42	0	0	0	0	0
a7BRSTR	0.019	0.135	0	1	7.21	50.60	162	116	46	0	0	0	0	0	0	0

w = weaner, y = yearling, a2 – a7 = adult two-year old to sever-year old;

Table 4. Summary of breech strike (BRSTR) rates by year (flystrike season) and sheep class. The breech strike traits are recorded as the proportion of animals in the flock struck during the flystrike 'season' (approximately October to April inclusive).

Flystrike	Weaner		Yearling		Adult (mixed ages)		Weighted
season	n	wBRSTR	n	yBRSTR	n	aBRSTR	average BRSTR
2005-06	172	0.163	0	0	0	-	0.163
2006-07	408	0.257	623	0.075	0	-	0.147
2007-08	241	0.241	385	0.130	605	0.233	0.202
2008-09	342	0.114	231	0.039	621	0.068	0.076
2009-10	510	0.143	336	0.012	717	0.049	0.072
2010-11	0	-	497	0.010	830	0.018	0.015
2011-12	337	0.131	0	-	405	0.140	0.136
2012-13	466	0.185	341	0.085	403	0.209	0.165
2013-14	442	0.134	460	0.111	396	0.119	0.121
2014-15	476	0.258	438	0.132	409	0.188	0.195
Total	3394	0.181	3311	0.076	4386	0.116	0.123
LTA annual rainfall = 785mm, LTA rainfall during fly season (Oct-Apr) = 540mm							

Figure 5 shows arithmetic mean weaner breech strike rate of sire progeny groups, ranked within years and with across-year link sires indicated. Across all years of the study period, progeny group breech strike rates ranged from 0% (one sire in 2013) to 97% (one sire in 2006). The wide variation in breech strike rates observed, both within and between years, between sire progeny groups is strongly suggestive of both environmental and genetic components to breech strike resistance or susceptibility.

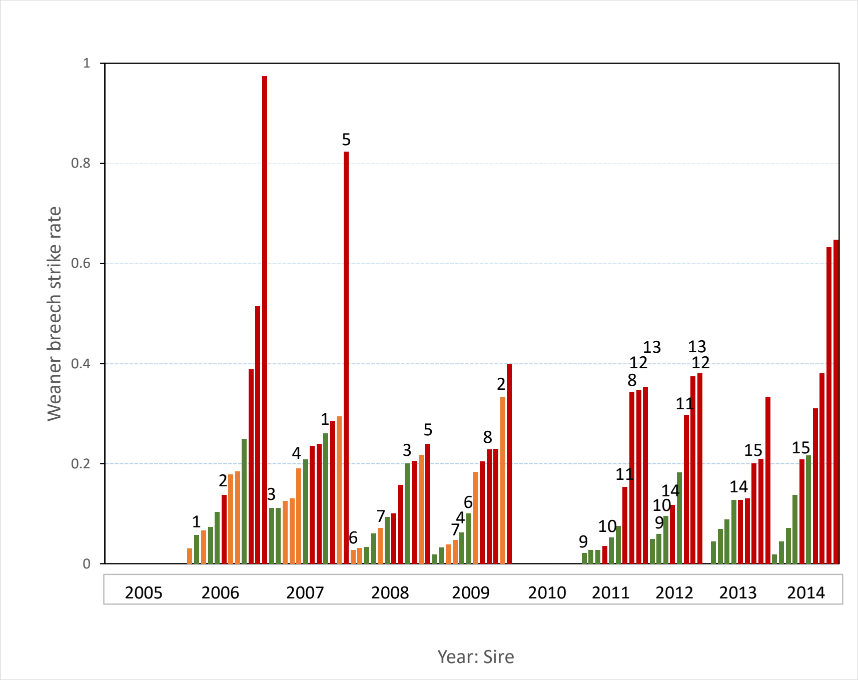

Figure 5. Arithmetic mean weaner breech strike among sire's progeny groups. Corresponding numbers across years indicate link sires. Red bars indicate Control/Susceptible line sires; orange bars indicate Commercial line sires; and green bars indicate Intense/Resistant line sires. Note, there were insufficient flystrike data collected in 2005, and no mating conducted in 2010.

Wrinkle, wool cover, and other breech traits. Table 5 shows summary statistics for the main wrinkle, wool cover and other breech-related traits recorded up to and including yearling age. Except for pDAG and pURINE, all of these traits approximated normality. pDAG and pURINE were subsequently logarithm transformed prior to any statistical analysis.

Fleece traits. Table 6 is a summary of yearling fleece traits, post-weaning WEC and body weight up to and including yearling age, and Table 7 is a summary of two-year old adult fleece traits. Among the fleece traits, only yFLROT did not approximate normality and so was logarithm transformed prior to statistical analysis. pWEC was also logarithm transformed.

Table 5. Summary statistics for wrinkle, wool cover, and other breech-related traits up to and including yearling age (b = birth, m = marking, p = post-weaning, y = yearling, NWR = neck wrinkle, BWR = body wrinkle, BRWR = breech wrinkle, CCOV = crutch cover, BCOV = breech cover, BW = breech bare width, BD = breech bare depth, TL = tail length, CBL = cannon bone length, DTL = docked tail length, DAG = dag and URINE = urine stain).

											n (birth year					
Trait	Mean	Sd	Min	Max	Skew	Kurt	Total	2005	2006	2007	2008	2009	2011	2012	2013	2014
bNWR (1-5)	2.57	0.77	1	5	0.06	-0.07	1524	0	417	249	346	512	0	0	0	0
bBWR (1-5)	2.18	0.85	1	5	0.32	-0.37	1648	124	417	249	346	512	0	0	0	0
bBRWR (1-5)	2.30	0.90	1	5	0.43	-0.12	1648	124	417	249	346	512	0	0	0	0
bCCOV (1-5)	3.55	0.70	1	5	-0.10	-0.09	1648	124	417	249	346	512	0	0	0	0
bBCOV (1-5)	4.49	0.62	2	5	-0.94	0.42	1524	0	417	249	346	512	0	0	0	0
mNWR (1-5)	2.72	0.89	1	5	0.04	-0.27	3257	0	417	249	346	512	341	467	447	478
mBWR (1-5)	2.37	0.95	1	5	0.27	-0.41	3901	644	417	249	346	512	341	467	447	478
mBRWR (1-5)	2.38	1.02	1	5	0.41	-0.49	3901	644	417	249	346	512	341	467	447	478
mCCOV (1-5)	3.50	0.74	1	5	0.06	-0.20	3901	644	417	249	346	512	341	467	447	478
mBCOV (1-5)	4.39	0.66	1	5	-0.81	0.41	3257	0	417	249	346	512	341	467	447	478
mBW (mm)	26	10	0	65	0.13	0.13	2913	0	417	249	345	512	0	466	447	477
mBD (mm)	36	19	0	110	0.43	0.64	2916	0	417	249	346	512	0	467	447	478
mTL (mm)	237	30	90	360	0.04	0.29	3279	118	406	244	333	503	324	450	437	464
mCBL (mm)	165	13	120	235	-0.02	0.28	1653	118	415	249	345	526	0	0	0	0
pNWR (1-5)	2.39	0.99	1	5	0.46	-0.18	3021	643	398	237	339	504	0	461	439	0
pBWR (1-5)	2.00	0.86	1	5	0.72	0.43	3021	643	398	237	339	504	0	461	439	0
pBRWR (1-5)	2.75	1.11	1	5	0.28	-0.62	3842	644	397	237	339	504	341	465	439	476
pCCOV (1-5)	3.47	0.75	1	5	0.17	-0.25	3842	644	397	237	339	504	341	465	439	476
pBCOV (1-5)	3.96	0.85	1	5	-0.44	-0.35	3842	644	397	237	339	504	341	465	439	476
pBW (mm)	39	14	0	100	0.67	0.23	3843	644	397	238	339	504	341	465	439	476
pBD (mm)	43	16	0	155	0.65	1.44	3842	643	397	238	339	504	341	465	439	476
pDTL (mm)	51	10	20	80	0.15	-0.12	915	0	0	0	0	0	0	0	439	476
pDAG (1-5)	1.44	0.67	1	5	1.71	3.45	3321	124	402	237	335	507	341	463	437	475
pURINE (1-5)	1.48	0.71	1	4	1.33	1.07	1555	0	0	131	160	236	341	244	205	238
yFACE (1-5)	2.84	0.81	1	6	0.69	0.66	3672	512	383	231	336	500	341	461	433	475
yNWR (1-5)	2.76	0.82	1	5	0.14	0.01	3781	625	382	231	334	496	339	461	439	474
yBWR (1-5)	2.31	0.88	1	5	0.20	-0.33	3778	625	382	231	334	496	339	461	436	474
yBRWR (1-5)	2.54	0.95	1	5	0.42	-0.04	3780	625	383	231	334	496	341	460	436	474
yCCOV (1-5)	3.58	0.61	2	5	0.20	-0.42	1916	625	383	231	336	0	341	0	0	0
yBCOV (1-5)	4.12	0.76	1	5	-0.52	-0.09	2873	625	383	231	336	496	341	461	0	0
yBW (mm)	48	14	15	100	0.46	0.03	1915	625	382	231	336	0	341	0	0	0
yBD (mm)	52	14	0	120	0.21	1.28	1914	625	381	231	336	0	341	0	0	0

b = birth, m = marking, p = post-weaning, y = yearling

Assessed traits scored on 1-5 scale as per AWI/MLA Visual Sheep Scores (2013 or earlier version) where 1 = least expression and 5 = most expression

Table 6. Summary statistics for body weight (WT) traits up to and including yearling age, post-weaning worm egg count (WEC), and yearling fleece traits.

								n (birth year)								
Trait	**Mean**	**Sd**	**Min**	**Max**	**Skew**	**Kurt**	**Total**	**2005**	**2006**	**2007**	**2008**	**2009**	**2011**	**2012**	**2013**	**2014**
bWT (kg)	4.1	0.8	1.1	8	-0.02	0.19	4081	123	501	304	452	693	447	535	496	530
mWT (kg)	11.1	2.8	4.6	20	0.46	-0.08	915	0	0	0	0	0	0	468	447	0
wWT (kg)	22.7	4.8	9.5	42.4	0.20	-0.06	3334	124	403	242	340	502	341	466	438	478
pWT (kg)	26.1	6.4	9.5	47.5	0.16	-0.42	3496	643	399	237	338	506	0	462	439	472
pWEC (epg)	1444	1739	0	25720	3.01	19.67	3177	0	392	236	332	500	341	461	439	476
yWT (kg)	32.8	9.2	14	61.5	0.30	-0.38	3761	621	380	224	333	495	339	458	437	474
yCOL (1-5)	2.87	0.66	1	5	-0.12	0.22	3672	512	383	231	336	500	341	461	433	475
yCRIMP (1-5)	2.80	0.70	1	5	0.23	-0.08	3672	512	383	231	336	500	341	416	433	475
yFLROT (1-5)	1.19	0.51	1	5	2.77	7.31	3672	512	383	231	336	500	341	416	433	475
yGFW (kg)	2.52	0.73	0.66	5.49	0.25	-0.35	3775	632	384	230	336	494	341	456	433	469
yCFW (kg)	1.98	0.55	0.54	4.12	0.17	-0.39	3773	632	383	230	336	493	341	456	433	469
yYLD (%)	79.1	4.4	60.5	92.1	-0.26	0.12	3795	636	383	231	336	500	341	460	433	475
yFD (µm)	15.50	1.12	12.2	20.5	0.40	0.28	3795	636	383	231	336	500	341	460	433	475
ySDFD (µm)	2.96	0.37	2.1	5.69	1.34	3.62	3795	636	383	231	336	500	341	460	433	475
yCVD (%)	19.1	2.3	13.4	29.55	0.85	1.25	3795	636	383	231	336	500	341	460	433	475
yCURV (°/mm)	104	12	64.7	142.42	0.11	0.01	3795	636	383	231	336	500	341	460	433	475
ySL (mm)	75.4	14.3	31.4	128	0.17	-0.22	2303	512	383	231	336	500	341	0	0	0
ySS (N/kTex)	34.3	8.8	7.1	82.4	0.70	2.01	2303	512	383	231	336	500	341	0	0	0

b = birth, m = marking, w = weaning, p = post-weaning, y = yearling, a2 = adult 2year old, COL = greasy wool colour, CRIMP = wool character, FLROT = fleece rot, GFW = greasy fleece weight, CFW = clean fleece weight, YLD = yield, FD = mean fibre diameter, SDFD = standard deviation of fibre diameter, CVD = coefficient of variation of fibre diameter, CURV = mean fibre curvature, SL = staple length, SS = staple strength

Table 7. Summary statistics for two-year old adult (a2) fleece traits, females only.

								n (birth year)								
Trait	**Mean**	**Sd**	**Min**	**Max**	**Skew**	**Kurt**	**Total**	**2005**	**2006**	**2007**	**2008**	**2009**	**2011**	**2012**	**2013**	**2014**
a2COL	2.68	0.79	1	5	-0.26	-0.21	1222	0	147	100	0	108	129	244	204	0
a2CRIMP	2.55	0.79	1	5	0.07	-0.09	1222	0	147	100	0	108	129	244	204	0
a2GFW	3.09	0.59	1.55	6.05	0.62	0.73	1941	568	147	99	153	108	126	243	204	0
a2CFW	2.51	0.48	1.19	5.14	0.57	0.82	1934	566	147	99	153	108	126	243	204	0
a2YLD	81.35	3.96	65.6	92.4	-0.28	0.05	1961	577	147	100	162	108	129	244	204	0
a2FD	17.15	1.25	13.9	23.6	0.57	1.01	1961	577	147	100	162	108	129	244	204	0
a2SDFD	2.96	0.35	2.17	5.3	1.29	3.86	1961	577	147	100	162	108	129	244	204	0
a2CVD	17.3	1.8	13.02	25.38	0.73	0.85	1961	577	147	100	162	108	129	244	204	0
a2CURV	99.02	11.77	63.65	144.08	0.19	0.18	1961	577	147	100	162	108	129	244	204	0
a2SL	79.87	9.78	52	115	0.24	0.38	695	0	147	100	162	108	129	0	0	0
a2SS	36.24	7.58	17.9	76.5	0.56	1.58	695	0	147	100	162	108	129	0	0	0

a2 = adult two-year old, COL = greasy wool colour, CRIMP = wool character, GFW = greasy fleece weight, CFW = clean fleece weight, YLD = yield, FD = mean fibre diameter, SDFD = standard deviation of fibre diameter, CVD = coefficient of variation of fibre diameter, CURV = mean fibre curvature, SL = staple length, SS = staple strength

5.2.2 Phenotypes

Founder ewes. Marking age BWR, BRWR and CCOV were the three traits used to select and assign the industry ewe lambs to selection lines. Mean and standard deviation for those three traits for the 2005 drop ewe lambs purchased from industry flocks was 2.32 (0.85), 2.28 (1.02) and 2.99 (0.70) for mBWR mBRWR and mCCOV respectively. Averaged across the properties of origin, the Control and Commercial lines were not significantly different from each other, and both were significantly different to the Intense line (mBWR, Control 2.55 (0.05), Commercial 2.56 (0.05) and Intense 1.74 (0.05); mBRWR, Control 2.60 (0.06), Commercial 2.63 (0.06), and Intense 1.54 (0.06); mCCOV, Control 3.02 (0.05), Commercial 3.05 (0.05), and Intense 2.80 (0.05), all $P<0.001$). Although all three traits exhibited statistically significant differences between the lines, the magnitude of the difference was considerably greater for the two wrinkle traits than mCCOV (approximately 0.8 and 1.1 for mBWR and MBRWR respectively, compared to approximately 0.2 of a score for mCCOV). Figure 6 shows selection line means for the 11 founder flocks for the three traits used to assign ewe lambs to lines.

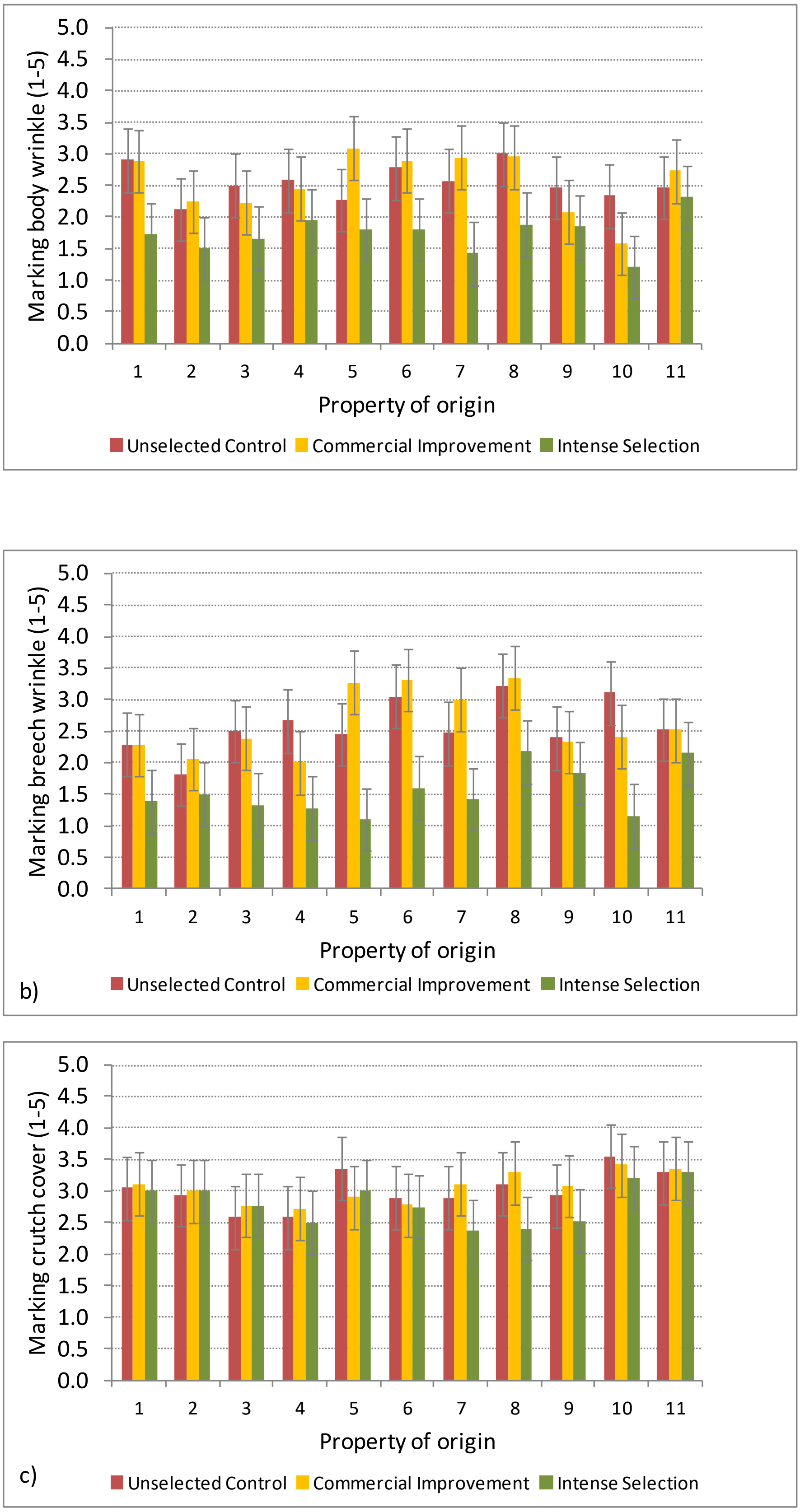

Figure 6. Selection line means for a) marking body wrinkle, b) marking breech wrinkle, and c) marking crutch cover, of ewe lambs from the 11 properties that contributed foundation industry animals. Error bars are s.e.d.

Selection lines. Phenotypic differences between selection lines over the life of the study period in wBRSTR, yBRWR, pDAG and yBCOV are demonstrated in Figures 7, 8, 9, and 10 respectively. Breech strike rates (Figure 7) and breech wrinkle (Figure 8) within the Control (Phase I) and Susceptible (Phase II) lines were consistently higher than the other selection lines in their respective phases of the study. For all four traits, the Commercial line, which only existed in Phase I, was similar to the Intense line. pDAG was relatively low and varied little between lines throughout the study period (Figure 9). yBCOV was a key selection criterion during Phase I for the study and there is suggestion the lines were diverging over time in that period but was less important during Phase II (Figure 10). The change in flock structure in 2010 impacted BRWR in the population retained in that the (retained) finer woolled animals were more wrinkly than the broader woolled animals that were culled.

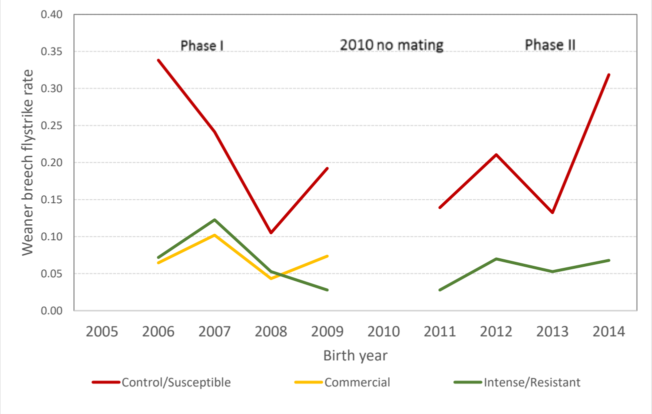

Figure 7. Phenotypic selection line differences in weaner breech strike (wBRSTR) among the Control, Commercial and Intense lines (Phase I), and Susceptible and Resistant lines (Phase II). Note, no wBRSTR data in 2005 (progeny treated with preventative chemical) or 2010 (no mating).

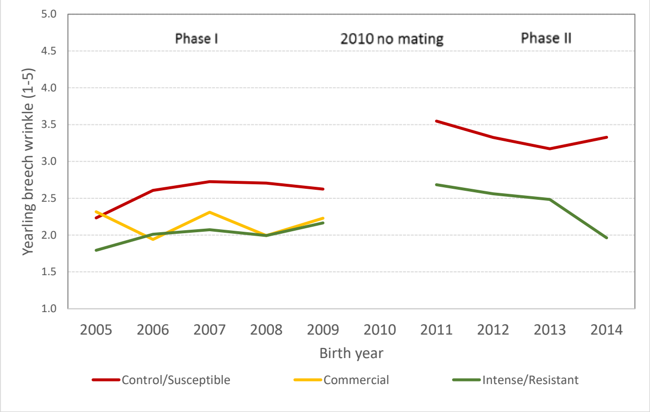

Figure 8. Phenotypic selection line differences in yearling breech wrinkle among the Control, Commercial and Intense lines (Phase I), and Susceptible and Resistant lines (Phase II).

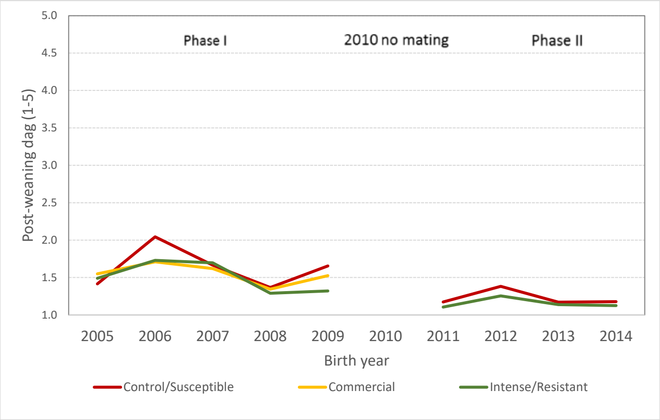

Figure 9. Phenotypic selection line differences in post-weaning dag among the Control, Commercial and Intense lines (Phase I), and Susceptible and Resistant lines (Phase II).

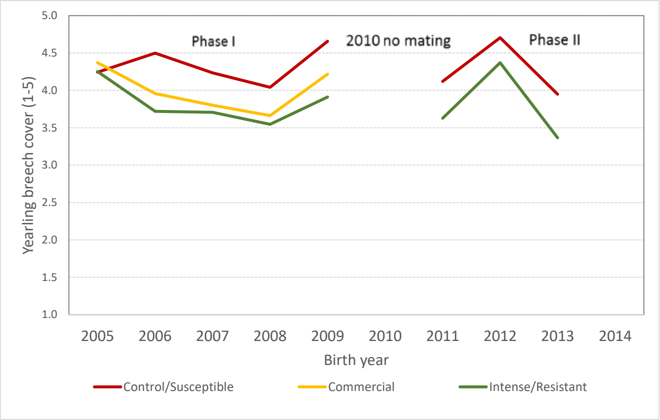

Figure 10. Phenotypic selection line differences in yearling breech cover among the Control, Commercial and Intense lines (Phase I), and Susceptible and Resistant lines (Phase II).

Fixed effects by age. Details of the fixed factors affecting the wrinkle, wool cover and associated traits at birth, marking, post-weaning and yearling ages are shown in Tables 8, 9, 10, and 11 respectively.

Birth traits. bNWR, bBWR, bBRWR, bCCOV and bBCOV were recorded at birth during lambing rounds up to and including 2009, after which this practice was discontinued. Selection line was a significant effect on all three of the wrinkle traits recorded at birth (all P<0.001), but selection line differences in bCCOV and bBCOV were not significant (Table 8). bBWR and bBRWR were the traits for which the selection lines were most different: Control line animals were approximately 0.3 score more wrinkly than Intense line animals for both bBWR and bBRWR. Sex was a significant effect on bBWR, bCCOV and bBCOV with females tending to be more wrinkly, and with greater wool cover than males. Birth type was a significant effect on all 5 of the traits recorded at birth, with singletons tending to be more wrinkly and with less wool coverage than multiples. bBCOV was the only trait for which age of dam was a significant effect, and lambs born to maiden dams exhibited less wool cover than lambs born to adult dams. Management group, of which birth year was a key component, was a significant effect on all of the birth traits. Birth weight was a significant effect on all traits except bCCOV whereby heavier lambs tended to be more wrinkly and have less wool cover on the breech and crutch.

Table 8. Summary of factors affecting wrinkle and wool cover traits recorded at birth, including predicted group means (s.e.) for significant line, sex, birth type, and age of dam effects.

Trait	**bNWR**	**bBWR**	**bBRWR**	**bCCOV**	**bBCOV**
Line	***	***	***	ns	ns
Control	2.69 (0.06)	2.37 (0.06)	2.45 (0.06)		
Commercial	2.60 (0.05)	2.16 (0.05)	2.36 (0.05)		
Intense	2.42 (0.05)	2.02 (0.05)	2.09 (0.06)		
Sex	ns	*	ns	***	***
Female		2.22(0.02)		3.63 (0.02)	4.77 (0.02)
Male		2.13 (0.03)		3.46 (0.02)	4.22 (0.02)
Btype	***	***	***	**	**
Single	2.64 (0.02)	2.25 (0.02)	2.37 (0.02)	3.51 (0.02)	4.45 (0.02)
Multiple	2.40 (0.04)	2.00 (0.05)	2.10 (0.04)	3.66 (0.04)	4.58 (0.03)
Dage	ns	ns	Ns	ns	*
Maiden					4.41 (0.04)
Adult					4.52 (0.04)
Mgp	***	***	***	***	***
bWT	***	***	***	ns	***
Significant interactions	Btype.Mgp**	Line.Btype***	Line.Btype**		Line.Sex* Sex.Dage** Sex.Mgp***

Line = selection line, Btype = birth type, Dage = age of dam, Mgp = management group, bWT = birth weight
*** P<0.001, ** P<0.01, * P<0.05, ns not significant

Marking traits. Eight marking age traits are reported here, being mNWR, mBWR, mBRWR, mCCOV, mBCOV, mBW, mBD, and TL. In most years mWT was not recorded, but in Phase I CBL was recorded, and mAGE was known for all progeny except the 2005 drop. Factors affecting the marking age traits are detailed in Table 9. Selection lines were significantly different for all eight of the marking age traits (all P<0.001). Control (Phase I) or Susceptible (Phase II) line animals were less wrinkly than Intense (Phase I) or Resistant (Phase II) animals by approximately 0.5 - 1.0 score. The line differences for the assessed wool cover traits (mCCOV and mBCOV) were less than for wrinkle, ranging from 0.2 - 0.6 score. For the measured breech traits, the line differences were greater for mBD than mBW, and were less than 10 mm. The Commercial line (Phase I) consistently lay between the Control and Intense lines for all traits. During Phase I, Control line animals had shorter tails than the Commercial and Intense lines (by approximately 15 mm), and in Phase II the Susceptible line had shorter tails than the Resistant line (by approximately 10 mm).

Sex was a significant effect on all marking age traits except mBRWR and TL. Females tended to have less wrinkle than males by about 0.1 score. Wool cover records relating to sex effects were in conflict. Assessed mCCOV and mBCOV indicated females had greater wool cover than males, but the measured mBW and mBD were the opposite, with females having greater bare area by 4-8 mm. This may simply be a physiological effect in that the operators attempted to score breech cover independent of the sex of the animal.

Birth-rearing type was a significant effect on all traits recorded at marking. Lambs born and reared single (S) were approximately 0.7 score more wrinkly than those born and reared multiple (MM). S lambs tended to have lower wool cover scores than MM lambs by approximately 0.1 score or 3-5 mm for the measured traits. S lambs had TL approximately 20 mm longer than MM lambs, despite adjustment for mAGE and mCBL. MS lambs tended to be intermediate between S and MM lambs for all marking age traits.

Age of dam was a significant effect on the three wrinkle traits, mCCOV, mBW and TL, but not mBCOV or mBD. Lambs born to adult dams tended to be more wrinkly (by about 0.1 - 0.2 score) and have longer TL (by approximately 8 mm) than those born to maiden dams. Management group and scorer were consistently significant effects on all of the marking age traits. AGE and/or CBL affected some of the marking age traits whereby older and/or larger animals tended to have more wrinkle, lower wool cover and longer tails (see Table 8.).

Post-weaning. Ten traits were recorded at post-weaning. In addition to the wrinkle and wool cover traits, pDAG and pURINE, as well as wBRSTR are included here (Table 10).

The selection lines were significantly different for wBRSTR (Phase I, Control 22.3%, Commercial 9.4%, intense 7.0%; Phase II Susceptible 20.1% and Resistant 5.4%, P<0.001). Mulesing was a significant effect on wBRSTR (P<0.001). Females exhibited higher wBRSTR than males (P<0.001), and animals of birth-rearing type S or MS had lower wBRSTR than animals of MM type. Management group and wWT were also significant effects on wBRSTR.

Again, all of the indicator traits were affected by selection line. In Phase I, Control line animals were more wrinkly than those in the Intense line, with Commercial's intermediate (range approximately 0.3 – 0.7), and in Phase II animals in the Susceptible line were more wrinkly than those in the Resistant line (range approximately 0.6 - 1.2). Line differences were greater for pBRWR than pNWR and pBWR. The selection lines were also significantly different for breech and crutch cover, both assessed and measured, with the difference greater during Phase I (approximately 0.6 score for CCOV and BCOV, and 10 - 14 mm) than Phase II (approximately 0.3 score and 2 - 5 mm). In both Phases of the study, animals in the selected lines had higher pDAG and pURINE scores than the Controls or Susceptible line animals, both by approximately 0.1-0.3 score.

Mulesing was a significant effect on all of the post-weaning breech and wrinkle traits except pCCOV. The mulesing effects on pNWR and pBWR were small, but statistically significant (approximately 0.1 score). In comparison, mulesing reduced pBRWR by almost 1.0 score, and pBCOV by approximately 0.3 score. Measured pBW and pBD were increased by approximately 9 and 2 mm respectively by mulesing. Mulesing reduced pDAG by approximately 0.1 score and pURINE by approximately 0.5 score.

Sex was a significant effect on pNWR, pBRWR, and all of the wool cover traits. Converse to the marking age records, females were more wrinkly than males at post-weaning, and as with marking age, the sex effects on the assessed and measured breech cover traits were contradictory. That is, although pBCOV was higher among females than males by approximately 0.2 score, the measured BW and BD indicated the opposite (i.e. greater BW and BD among females than males).

Both birth-rearing type and age of dam were significant effects on all three of the wrinkle traits, although the birth-rearing type effect was greater (approximately 0.4 score, P<0.001) than the age of dam effect (approximately 0.1 score, P<0.01 and P<0.05). Animals with birth-rearing type S and those with adult dams were more wrinkly than those of MM birth rearing type and maiden dams. pURINE effects of birth-rearing type were in favour of MS and MM over S animals which may be indirectly associated with breech wrinkle. Again, management group, effectively a year effect, was significant for all of the post-weaning traits. Where there were significant bodyweight effects on post-weaning traits, heavier animals tended to be more wrinkly, but with lower wool cover and pDAG.

Yearling. Eight yearling age traits are reported, these being the seven previously recorded wrinkle and wool cover traits, as well as yFACE (Table 11). Again, selection line was a significant effect on all traits, with Phase I Controls and Phase II Susceptible animals approximately 0.6 - 1.0 score more wrinkly than Phase I Intense and Phase II Resistant line animals (P<0.001). The magnitude of difference between lines for yCCOV and yBCOV reflected the respective post-weaning traits (i.e. line difference of approximately 0.4 - 0.6 score, P<0.001). In Phase I the line effect on yFACE effect was approximately 0.4 score, whereas in Phase II it was only 0.1 score.

The effect of mulesing on yBRWR was approximately 0.7 score (P<0.001), and there remained a small, yet statistically significant effect on yBWR (P<0.01). Mulesing reduced yBCOV and yBW (both P<0.001), but not yCCOV or yBD.

As with the earlier ages, birth-rearing type and age of dam were significant effects on the wrinkle traits with S animals more wrinkly than MS and MM animals by approximately 0.2 - 0.4 score (all P<0.001), and animals born to adult dams more wrinkly than those born to maiden dams by approximately 0.1 score. There were no birth-rearing type or age of dam effects on any of the wool cover traits. Management group remained a significant effect on all yearling age traits (P<0.001). Again, where there were significant age and/or bodyweight effects, with older and/or heavier animals tending to be more wrinkly, and have lower wool cover on the crutch, breech and face.

Table 9. Summary of factors affecting breech traits recorded at marking, including predicted group means (s.e.) for significant line, sex, birth type, and age of dam effects.

Trait	**mNWR**	**mBWR**	**mBRWR**	**mCCOV**	**mBCOV**	**mBW**	**mBD**	**TL**
Line	***	***	***	***	***	***	***	***
Phase I Control	2.95 (0.03)	2.71 (0.03)	2.73 (0.03)	4.10 (0.02)	4.72 (0.02)	24.1 (0.3)	31.6 (0.5)	225.4 (0.8)
Phase I Commercial	2.49 (0.03)	2.02 (0.03)	2.27 (0.03)	3.60 (0.02)	4.44 (0.02)	27.3 (0.3)	36.1 (0.5)	240.3 (0.7)
Phase I Intense	2.36 (0.03)	1.95 (0.03)	1.90 (0.03)	3.52 (0.02)	4.28 (0.02)	29.2 (0.3)	39.4 (0.5)	239.1 (0.7)
Phase II Susceptible	3.24 (0.02)	2.99 (0.02)	3.08 (0.02)	3.61 (0.02)	4.46 (0.02)	24.8 (0.3)	38.2 (0.4)	233.9 (0.6)
Phase II Resistant	2.49 (0.02)	2.05 (0.02)	2.02 (0.02)	3.37 (0.02)	4.21 (0.02)	26.2 (0.3)	32.5 (0.4)	242.2 (0.6)
Sex	***	***	ns	***	***	***	***	ns
Female	2.65 (0.02)	2.34 (0.02)		3.64 (0.01)	4.49 (0.01)	30.3 (0.2)	37.5 (0.3)	
Male	2.80 (0.02)	2.43 (0.02)		3.53 (0.01)	4.29 (0.01)	22.2 (0.2)	33.8 (0.3)	
Birth rearing type	***	***	***	***	***	***	***	***
S	3.02 (0.02)	2.66 (0.02)	2.69 (0.02)	3.54 (0.01)	4.33 (0.01)	27.8 (0.2)	37.7 (0.3)	245.5 (0.5)
MS	2.57 (0.04)	2.26 (0.04)	2.29 (0.05)	3.53 (0.04)	4.37 (0.03)	26.2 (0.5)	35.1 (0.7)	232.2 (1.4)
MM	2.25 (0.02)	1.92 (0.02)	1.91 (0.03)	3.69 (0.02)	4.51 (0.02)	23.7 (0.2)	32.5 (0.4)	222.4 (0.7)
Age of dam	***	***	**	**	ns	*	ns	***
Maiden	2.62 (0.03)	2.28 (0.03)	2.31 (0.03)	3.62 (0.03)		25.6 (0.4)		231.1 (1.0)
Adult	2.76 (0.01)	2.42 (0.01)	2.43 (0.02)	3.58 (0.01)		26.5 (0.2)		238.6 (0.4)
Management group	***	***	***	***	***	***	***	***
Scorer	***	***	***	***	*	***	***	-
AGE	ns	ns	*	***	ns	***	***	***
mCBL	***	*	**	ns	ns	***	***	***
Significant interactions		Line.Brtype*** Line.Mgp***	Line.Brtype*** Line.Mgp**	Line.Brtype*** Line.Mgp***	Line.Sex*** Sex.Mgp***	Line.Sex*** Line.Mgp* Sex.Brtype* Sex.Mgp***	Line.Sex*** Line.Mgp*** Sex.Mgp***	Sex.Mgp** Brtype.Mgp* Dage.Mgp**

Line = selection line, Brtype = birth-rearing type, Dage = age of dam, Mgp = management group, CBL = cannon bone length (a proxy for frame size), S = born and reared single, MS = born multiple and reared single, MM = born and reared multiple

*** P<0.001, ** P<0.01, * P<0.05, ns not significant

Table 10. Summary of factors affecting breech traits recorded at post-weaning, including predicted group means (s.e.) for significant line, mulesing, sex, birth type, and age of dam effects.

Trait	pNWR	pBWR	pBRWR	pCCOV	pBCOV	pBW	pBD	pDAG	pURINE	wBRSTR
Line	***	***	***	***	***	***	***	***	***	***
Phase I, Control	2.44 (0.03)	2.11 (0.03)	2.74 (0.03)	3.70 (0.02)	4.42 (0.02)	37.1 (0.3)	41.0 (0.4)	1.67	1.82	0.223
Phase I, Commercial	2.12 (0.03)	1.94 (0.02)	2.28 (0.03)	3.19 (0.02)	3.99 (0.02)	43.2 (0.3)	48.4 (0.4)	1.54	1.55	0.094
Phase I, Intense	1.97 (0.03)	1.84 (0.02)	2.04 (0.03)	3.04 (0.02)	3.74 (0.02)	47.0 (0.3)	55.3 (0.4)	1.47	1.45	0.070
Phase II, Susceptible	3.40 (0.03)	2.81 (0.03)	3.87 (0.02)	3.99 (0.02)	4.31 (0.02)	31.0 (0.3)	40.3 (0.3)	1.16	1.46	0.201
Phase II, Resistant	2.72 (0.03)	1.99 (0.03)	2.66 (0.02)	3.60 (0.02)	3.98 (0.02)	32.6 (0.3)	45.3 (0.4)	1.22	1.18	0.054
Mules	**	*	***	ns	***	***	*	***	***	***
Mulesed	2.42 (0.03)	2.07 (0.02)	2.06 (0.03)		3.85 (0.02)	44.1 (0.3)	44.6 (0.4)	1.25	1.01	0.002
Unmulesed	2.51 (0.02)	2.13 (0.02)	3.01 (0.01)		4.16 (0.01)	34.9 (0.2)	46.1 (0.2)	1.40	1.48	0.166
Sex	**	ns	*	***	***	***	***	**	-	***
Female	2.52 (0.02)		2.82 (0.02)	3.51 (0.01)	4.19 (0.01)	42.2 (0.2)	46.4 (0.3)	1.34		0.161
Male	2.45 (0.023)		2.74 (0.02)	3.59 (0.01)	3.98 (0.02)	31.5 (0.2)	45.0 (0.3)	1.38		0.085
Birth rearing type	***	***	***	ns	ns	ns	ns	ns	*	***
S	2.62 (0.02)	2.25 (0.02)	2.96 (0.02)						1.44	0.138
MS	2.35 (0.05)	1.95 (0.04)	2.71 (0.05)						1.32	0.122
MM	2.24 (0.03)	1.87 (0.03)	2.48 (0.02)				43.2 (0.4)		1.35	0.099
Age of dam	**	*	**	ns	ns	ns	ns	ns	ns	ns
Maiden	2.38 (0.04)	2.04 (0.04)	2.70 (0.03)							
Adult	2.51 (0.02)	2.13 (0.02)	2.81 (0.02)							
Management group	***	***	***	***	***	***	***	***	***	***
Scorer	**	ns	**	***	***	***	ns	ns	*	-
AGE	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
wWT	***	*	ns	***	***	***	***	***	ns	***
Significant interactions	Line.Sex*** Line.Brtype*** Line.Mgp** Mules.Mgp* Sex.Mgp***	Line.Sex*** Line.Brtype** Sex.Mgp***	Line.Mules*** Line.Sex** Line.Brtype* Line.Mgp** Mules.Brtype*** Mules.Mgp*** Sex.Mgp***	Line.Sex*** Sex.Mgp***	Line.Sex*** Mules.Sex*** Mules.Mgp** Sex.Mgp* Brtype.Dage*	Line.Mules*** Line.Sex** Line.Brtype** Mules.Sex*** Mules.Mgp*** Sex.Mgp***	Line.Sex*** Mules.Sex* Mules.Mgp* Sex.Mgp***	Line.Sex*** Mules.Mgp** Brtype.Mgp*	Line.Mules** Line.Mgp** Mules.Mgp*	Line.Mules*** Line.Sex*** Line.Mgp* Mules.Sex*** Mules.Brtype** Mules.Mgp*** Sex.Mgp**

Line = selection line, Brtype = birth-rearing type, Dage = age of dam, Mgp = management group, wWT = weaning bodyweight, S = born and reared single, MS = born multiple and reared single, MM = born and reared multiple; wBRSTR is count of breech strikes over the season so effectively this is proportion of struck animals in the class;
*** P<0.001, ** P<0.01, * P<0.05, ns not significant. Group means reported for pDAG, pURINE and wBRSTR are back-transformed values, therefore no s.e. is included.

Table 11. Summary of factors affecting breech traits recorded on yearlings, and combined yearling-adult breech strike (females only), including predicted group means (s.e.) for significant line, mulesing, sex, birth rearing type, and age of dam effects

Trait	yNWR	yBWR	yBRWR	yCCOV	yBCOV	yBW	yBD	yFACE	y-aBRSTR
Line	***	***	***	***	*	***	***	*	***
Phase I, Control	2.82 (0.03)	2.47 (0.03)	2.72 (0.03)	3.88 (0.02)	4.37 (0.02)	41.7 (0.5)	49.5 (0.5)	3.07 (0.02)	0.251
Phase I, Commercial	2.45 (0.02)	1.99 (0.03)	2.27 (0.03)	3.47 (0.02)	4.00 (0.02)	47.8 (0.5)	56.3 (0.5)	2.69 (0.02)	0.144
Phase I, Intense	2.26 (0.02)	1.80 (0.03)	2.09 (0.03)	3.32 (0.02)	3.77 (0.02)	51.0 (0.5)	60.5 (0.5)	2.64 (0.02)	0.088
Phase II, Susceptible	3.41 (0.02)	2.89 (0.02)	3.35 (0.02)	3.95 (0.04)	4.27 (0.02)	37.7 (0.8)	35.2 (0.9)	2.85 (0.02)	0.507
Phase II, Resistant	2.78 (0.02)	2.08 (0.02)	2.39 (0.02)	3.54 (0.03)	3.84 (0.02)	46.1 (0.7)	39.3 (0.7)	2.74 (0.02)	0.101
Mules	ns	**	***	ns	***	***	ns	ns	***
Mulesed		2.21 (0.03)	2.07 (0.03)		3.73 (0.02)	52.8 (0.4)			0.009
Unmulesed		2.29 (0.01)	2.76 (0.01)		4.15 (0.01)	41.9 (0.3)			0.300
Sex	*	ns	ns	*	ns	***	***	***	-
Female	2.77 (0.02)			3.64 (0.02)		50.1 (0.4)	54.6 (0.4)	2.60 (0.02)	
Male	2.82 (0.02)			3.52 (0.02)		41.1 (0.4)	47.5 (0.4)	2.98 (0.02)	
Birth rearing type	***	***	***	ns	ns	ns	ns	ns	ns
SS	2.93 (0.01)	2.42 (0.02)	2.74 (0.02)						
MS	2.72 (0.04)	2.15 (0.04)	2.55 (0.04)						
MM	2.57 (0.02)	2.02 (0.02)	2.36 (0.02)						
Age of dam	**	**	***	ns	ns	ns	ns	ns	ns
Maiden	2.69 (0.03)	2.17 (0.03)	2.50 (0.03)						
Adult	2.83 (0.01)	2.30 (0.01)	2.63 (0.01)						
Management group	***	***	***	***	***	***	***	***	-
Contemporary group	-	-	-	-	-	-	-	-	***
Scorer	**	*	ns	***	***	***	**	ns	-
AGE	ns	*	**	***	***	***	***	**	-
yWT	ns	ns	***	***	***	***	***	***	***
Significant interactions	Line.Brtype*** Line.Mgp** Mules.Mgp* Sex.Mgp***	Line.Brtype*** Line.Mgp*** Sex.Mgp***	Line.Brtype*** Line.Mgp* Mules.Mgp*** Sex.Brtype* Sex.Mgp***	Line.Mules** Line.Sex*** Line.Mgp*	Line.Sex*** Mules.Sex*** Mules.Mgp*** Sex.Mgp*** Dage.Mgp**	Line.Mules*** Line.Sex*** Mules.Sex*** Mules.Mgp*** Sex.Mgp***	Line.Sex*** Mules.Sex* Mules.Mgp* Sex.Mgp** Brtype.Mgp* Dage.Mgp***	Sex.Mgp***	

Line = selection line, Brtype = birth-rearing type, Dage = age of dam, Mgp = management group, yWT = yearling bodyweight, SS = born and reared single, MS = born multiple and reared single, MM = born and reared multiple; *** P<0.001, ** P<0.01, * P<0.05, ns not significant. Contemporary group for y-aBRSTR combined birth year and each consecutive additional year the animal remained in the flock. Group means reported for y-aBRSTR are back-transformed values, therefore no s.e. is included.

5.2.3 Fixed effects

Selection lines. In summary, in both phases of the study period there were significant selection line differences in breech strike itself, and the various indicator traits. The overall flystrike rates varied widely across years due to prevailing weather conditions. However, averaged across years, there was a three to four-fold difference in weaner breech strike between Control and Intense line animals in Phase I, and between Susceptible and Resistant line animals in Phase II. This bodes well for success in industry for selective breeding to improve breech strike resistance and thereby to reduce reliance on other means of control such as chemicals and mulesing.

The selection line differences observed arise from a combination of the one-off selection imposed through the founder ewes and the on-going selection applied over the course of the study period. The latter is a combination of genetic gain from the external sires used, and within-flock selection. It would appear (from Figures 8, 9, and 10) that the initial ewe selection achieved a phenotypic difference of approximately 0.4 score in yBRWR, no difference in yBCOV, and less than 0.1 score in pDAG. At the end of the study period, the selection line difference in yBRWR was more than 1.2 score for yBRWR, but for the several preceding years was consistently approximately 0.8 score. Without continuation of the selection program, it is unknown whether the large effect observed in the final year was an anomaly or not. At the end of the study period the selection line difference in yBCOV was approximately 0.5 score, and there was little, if any change in pDAG. Line effects were greater for yBCOV and pDAG at the end of Phase I of the study period than at the end of Phase II. This was likely due to the removal of the larger framed, broader woolled and subsequently plainer bodied ewes, and this was a set-back to the gains in those two traits. No judgements can be made about founder ewe effects on weaner breech strike because they were not phenotyped for that trait.

From a practical perspective, the selection process has achieved considerable changes in indicator traits, especially breech wrinkle. These are clearly changes sufficient to have marked impact on breech strike rates. The changes in breech wrinkle achieved by selection are similar to that achieved by mulesing. Similarly, for breech cover and breech bare depth, during Phase I when breech cover was the primary selection criterion, the gains achieved by selection were similar to those achieved by mulesing. During Phase II, effects of selection on breech cover and breech bare width remained to a degree, but they were not of the same magnitude as the effect of mulesing.

With the exception of the wool cover traits recorded at birth, there were significant differences between the selection lines in all traits and at all stages, up to and including yearling age. Line differences in the wrinkle traits were consistently lowest at birth, suggesting that birth is a less than optimal time to record wrinkle and wool cover traits for the purpose of breeding for breech strike resistance. Otherwise, marking, post-weaning and yearling ages are all appropriate ages to record these traits.

Mulesing effects. At post-weaning, and to a lesser degree at yearling age, there were small yet statistically significant effects of mulesing on neck and body wrinkle. The reason for this is unknown. It may be that operators inadvertently or subconsciously consider wrinkle all over the body when making assessments of wrinkle on a particular site. Or there may be some physiological impact of mulesing, for example that the impact of mulesing is a physical and/or psychological setback to the animal.

The effect of mulesing on breech wrinkle was greater at post-weaning than yearling age (approximately 1.0 score versus 0.7score), but there is a suggestion that the effect on breech cover was greater for yearlings than post-weaners. Ongoing effects of mulesing on breech wrinkle and breech cover into adulthood are of interest for lifetime resistance to flystrike, but further evaluation of adult ewes is complicated by the effects of (repeated) pregnancy and lactation (initially evaluated in WP468 TMS-06).

Evidence indicates that mulesing affects breech bare width, but has little, if any effect on breech bare depth. Given the effect of mulesing on breech strike rates, this might suggest that in assessing breech cover as a selection criterion to reduce breech strike, more attention should be paid to the width, than depth of the breech bare area. This is one point of difference with the current version of the Visual Sheep Scores (2013), which states that it is important in assessing breech cover to consider in combination both the width and depth of bare skin around the perineum. Correlations among breech strike, breech cover, and measured breech bare width and depth should be evaluated to determine whether a change to the current standard for assessing breech cover might be warranted.

Nevertheless, results obtained here from scoring animals for wrinkle and wool cover traits at marking and older ages provide general support for the current industry recommendations around age of measurement as stated in Visual Sheep Score (2013). Earlier versions of the standards described in Visual Sheep Scores (2013) were based partly on information obtained subsets of the Armidale and Mt Barker Breech Strike Genetic Resource flocks, and this analysis of the entire dataset supports current industry recommendations.

Comparison of selection with mulesing. Mulesing was conducted for the first 5 years of this study in order to obtain a comparison of breech strike rates from mulesing and selective breeding. Keeping in mind that 5 years is not a long time in sheep breeding terms, but that there was an initial screen-in of ewes to selection lines accompanied by across-flock and within-flock sire selection, a significant selection line effect on breech strike rate was observed, that was similar in magnitude to the effect of mulesing.

Mulesing reduced breech strike by approximately 90%. By comparison, selection reduced breech strike by approximately 60% in Phase I and 75% in Phase II. Of all the indirect selection criteria examined, mulesing changed BRWR the most (by approximately 1.0 score), followed by pURINE (by approximately 0.5 score). Selection also reduced BRWR (by 0.7 score in Phase I, and 1.2 score in Phase II).

Management group, sex, birth-rearing type and age-of-dam. Aside from selection line, of the fixed effects recorded here, and those that can be routinely recorded and adjusted for in genetic evaluation, birth-rearing type effects on wrinkle traits are perhaps the most important. Significant effects of birth-rearing type on neck, body and breech wrinkle were observed at all ages. They were greatest (approximately 0.70-0.75 score) at marking but remained statistically significant at post-weaning (0.30-0.45) and yearling ages (0.20-0.25). This is important information for the practice of genetic evaluation of wrinkle traits in industry. Without knowledge of birth-rearing type, estimates of genetic merit for wrinkle traits could be severely biased. Not only is this an issue for genetic evaluation in the Merino stud industry, but it also has implications for the accuracy of phenotypic selection that may be conducted in commercial ewe flocks. One redeeming feature of this birth-rearing type effect may be in the declining magnitude of the effect with age. The stud industry is perhaps more likely to record birth-rearing type and they are possibly also more likely to record wrinkle at marking age. Hence, they are in a better position to adjust for birth-rearing type. In commercial ewe flocks, producers are unlikely to have information on birth rearing type, but may make selection decisions later, perhaps after the yearling shearing and before first mating. The birth-rearing type effect appears to decline by yearling age and so it is less important to be able to accommodate it.

Age of dam was a small (approximately 0.1 score) but consistent effect on the three wrinkle traits from marking to at least yearling age. Effects of birth-rearing type and age of dam into adulthood warrant further investigation for their potential impact on lifetime wrinkle and subsequently, flystrike. It is thought these effects are likely associated with early life nutrition, both in utero and early post-natal, where singleton lambs born to adult dams have greater nutrition at their disposal than those lambs reared as multiples and/or to maiden dams. These better-grown lambs are more wrinkly, but also have lower wool cover on the perineal regions.

Management group effects are clearly an important effect on all of the breech and wrinkle traits. Much of the management group effect recorded here is birth-year, which can be accommodated by inclusion of across-year links in flocks where genetic evaluation is required. In commercial flocks, selections should be made within year groups to accommodate this type of environmental effect.

Sex effects on the wrinkle traits were usually small (<0.2 score), but statistically significant. Perhaps more important, the sex effects were inconsistent across the ages recorded, with females more wrinkly than males at birth and post-weaning, and males more wrinkly than females at marking and yearling ages. The reasons for these variable effects are not known. Sex effects on the wool cover traits were inconsistent between the assessed scores and measured traits, and this is likely a function of operator perceptions.

The data suggest that at post-weaning the variation in neck and body wrinkle is lower than at marking and yearling ages, and also lower than breech wrinkle at post weaning. This may be a function of the breeding objective and selection criteria (i.e. that breech wrinkle is a greater focus than neck and body wrinkle) or may be an indication that at post-weaning neck and body wrinkle was less discernible due to longer wool length at that stage. If the latter, this suggests that wrinkle scoring for neck and body wrinkle is relatively less effective when animals are ‘in the wool’ as opposed to in short wool (i.e. marking or off shears), and therefore should be discouraged as an industry practice.

Variance component partitioning. A variance partitioning exercise was conducted to identify the relative contribution to variation in weaner (Figure 11a) and yearling-adult breech strike (Figure 11b), of known fixed factors, indicator traits and genetic effects.

For the weaner trait, the fixed effects included selection line, mulesing, sex, birth-rearing type, age of dam, management group (incorporating birth year), and weaning weight (fitted as a linear covariate), and accounted for approximately 11% of variation in breech strike. The phenotypic component of the indicator traits of yBRWR, yBCOV, yCCOV, pDAG and pURINE together accounted for a further 15% of variation in breech strike, with pDAG and pURINE being the dominant characteristics. This is perhaps counter intuitive given other evidence indicates BRWR is a more important trait to breech strike than DAG. However, the statistical model used here includes genetic effects with animal fitted as a random effect. It is likely that most of the BRWR effect is incorporated into the additive genetic component (since it is known that BRWR is moderately heritable), while the DAG and URINE components are predominantly phenotypic rather than genetic (they have lower heritability than BRWR). The additive genetic variation contributed approximately 20% and this is effectively the heritability of breech strike. It is not possible to separate the additive genetic component further (i.e. to quantify the additive genetic component of the various indicator traits, or breech strike itself), because these traits are all highly polygenic and probably not independent of each other. Together, these known effects account for approximately 46% of the total variation in breech strike, with the remaining 54% of variation unexplained (i.e. error or residual).

There are some notable differences between the variance component partitioning of weaner and yearling-adult breech strike. The significant fixed effects on yearling-adult (female) breech strike included selection line, mulesing, contemporary group (birth-year, number of years retained, and exactly which years they were), and yearling bodyweight (fitted as a linear covariate). Sex was excluded because this trait only included females. Birth rearing type and age of dam were non-significant and hence were also excluded from the statistical model. The fixed effects on yearling-adult breech strike accounted for approximately double that of weaner breech strike. Most of this difference is likely due to the contemporary group effect. There was some re-ranking of the importance of the phenotypic component of the various indicator traits. For yearling-adult breech strike, the phenotypic component of breech wrinkle is more important than it was for weaners, and the importance of dag has declined. This is not unexpected because few adult ewes exhibit dag. The additive genetic component has increased to almost 27% for yearling-adult breech strike, so together, this makes residual variation in yearling-adult breech strike less than 40%. These results suggest that wrinkle is even more important for breech strike risk in adults than weaners, at both the phenotypic and genetic levels.

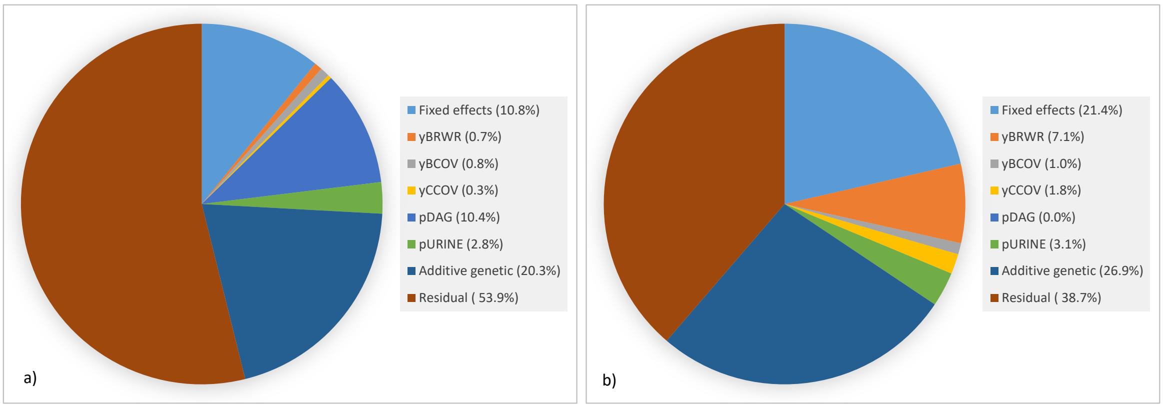

Figure 11. Relative contribution to variance in a) weaner breech strike (males and females), and b) yearling-adult (females only) for fixed effects, key indirect indicators of breech strike, genetics, and residual variation. For weaners, fixed effects included selection line, mulesing, sex, birth-rearing type, age-of-dam, management group (which incorporates birth year), and body weight. For yearling-adult females, fixed effects included selection line, mulesing, contemporary group (which incorporates birth year, number of years retained in the flock, and exactly which years they were), and yearling bodyweight.

Production traits. Tables 12 and 13 show the incidence of significant fixed effects on fleece and other production traits up to and including yearling age. The selection lines were significantly different for all fleece, body weight and disease traits except COL and SS. In general, the Control (Phase I) or Susceptible (Phase II) line animals tended to have lighter bodyweight, lower fibre diameter, higher fibre curvature, and shorter staple length than the Intense (Phase I) or Resistant (Phase II) line. The Susceptible line had slightly higher yearling fleece weight than the Resistant line.

There are several constituents to fleece weight, including body size/wool growing surface area; fibre density on the wool growing surface; and fibre dimensions (diameter and length). The Resistant line yearlings had slightly lower fleece weight than the Susceptible line, despite that their heavier bodyweight, broader fibre diameter and longer staple length. This suggests the Resistant line either have relatively lower fibre density, or more likely, less wool growing surface area (less skin wrinkle and less wool coverage at the points).

The selection lines were consistently significantly different in bodyweight, with the Resistant line being heavier than the Susceptible line: approximately 1kg at weaning and 2kg at yearling age. This might suggest that at least at a within flock level, body weight is potentially an indirect selection criterion that could make some degree of impact on breech strike risk.

Table 12. Summary of factors affecting bodyweight, post-weaning WEC and assessed fleece traits recorded on yearlings, including predicted group means (s.e.) for significant line, mulesing, sex, birth rearing type, and age of dam effects.

Trait	bWT	wWT	yWT	pWEC	yCOL	yCRIMP	yFLROT
Line	***	***	***	***	ns	*	***
Phase I, Control	3.98 (0.02)	20.5 (0.1)	27.5 (0.1)	905		2.92 (0.02)	1.22
Phase I, Commercial	4.18 (0.02)	21.9 (0.1)	30.3 (0.1)	847		2.83 (0.02)	1.26
Phase I, Intense	4.07 (0.02)	22.5 (0.1)	31.4 (0.1)	996		2.84 (0.02)	1.26
Phase II, Susceptible	4.22 (0.02)	23.1 (0.1)	37.8 (0.1)	416		3.12 (0.02)	1.16
Phase II, Resistant	4.25 (0.02)	24.2 (0.1)	39.6 (0.1)	487		2.65 (0.02)	1.05
Mules	-	**	ns	ns	ns	ns	ns
Mulesed		22.3 (0.1)					
Unmulesed		22.8 (0.1)					
Sex	***	***	***	*	***	ns	***
Female	4.07 (0.01)	22.1 (0.1)	32.6 (0.1)	597	2.93 (0.01)		1.19
Male	4.26 (0.01)	23.4 (0.1)	36.5 (0.1)	648	3.01 (0.01)		1.14
Birth type	***	-	-	-	-	-	-
Single	4.59 (0.01)						
Multiple	3.56 (0.02)						
Birth rearing type	-	***	***	ns	***	ns	***
SS		24.8 (0.1)	35.5 (0.1)		2.93 (0.01)		1.19
MS		22.6 (0.2)	34.4 (0.2)		2.95 (0.03)		1.16
MM		18.9 (0.1)	32.8 (0.1)		3.03 (0.02)		1.12
Age of dam	***	***	***	ns	ns	ns	ns
Maiden	3.86 (0.02)	21.8 (0.1)	33.6 (0.2)				
Adult	4.26 (0.01)	23.0 (0.1)	34.8 (0.1)				
Management group	***	***	***	***	***	***	***
Scorer	-	-	-	-	-	-	-
AGE	-	***	***	ns	ns	ns	ns
yWT	-	-	-	ns	ns	ns	ns
Significant interactions	Btype.Mgp*** Dage.Mgp***	Line.Sex*** Sex.Brtype* Sex.Mgp**	Line.Sex*** Mules.Sex** Sex.Brtype* Sex.Dage* Sex.Mgp***	Line.Sex*** Line.Mgp* Sex.Mgp*** Brtype.Mgp**	Line.Sex** Line.Brtype*** Sex.Mgp*** Brtype.Mgp***	Line.Brtype** Line.Mgp* Sex.Mgp***	Line.Brtype** Sex.Mgp* Brtype.Mgp**

Line = selection line, Brtype = birth-rearing type, Dage = age of dam, Mgp = management group, yWT = yearling bodyweight, SS = born and reared single, MS = born multiple and reared single, MM = born and reared multiple; *** P<0.001, ** P<0.01, * P<0.05, ns not significant; pWEC and yFLROT means are back-transformed therefore no se is reported

Table 13. Summary of factors affecting measured yearling fleece traits, including predicted group means (s.e.) for significant line, mulesing, sex, birth rearing type, and age of dam effects.

Trait	yGFW	yCFW	yYLD	yFD	ySDFD	yCVD	yCURV	ySL	ySS
Line	***	*	***	***	***	***	**	***	ns
Phase I, Control	2.21 (0.01)	1.75 (0.01)	79.9 (0.1)	14.98 (0.02)	2.89 (0.01)	19.38 (0.06)	109.9 (0.3)	73.8 (0.3)	
Phase I, Commercial	2.33 (0.01)	1.85 (0.01)	79.7 (0.1)	15.68(0.02)	2.84 (0.01)	18.14 (0.06)	104.1 (0.3)	79.3 (0.3)	
Phase I, Intense	2.44 (0.01)	1.93 (0.01)	79.5 (0.1)	16.03 (0.02)	2.97 (0.01)	18.61 (0.06)	100.1 (0.3)	82.9 (0.3)	
Phase II, Susceptible	2.94 (0.01)	2.27 (0.01)	77.7 (0.1)	15.33 0.02)	2.93 (0.01)	19.15 (0.04)	106.4 (0.2)	69.3 (0.6)	
Phase II, Resistant	2.87 (0.01)	2.23 (0.01)	77.9 (0.1)	15.51 (0.02)	2.90 (0.01)	18.75 (0.05)	103.6 (0.2)	77.0 (0.4)	
Mules	**	*	ns	ns	**	*	ns	ns	ns (P=0.077)
Mulesed	2.59 (0.01)	2.03 (0.01)			2.88 (0.01)	18.71 (0.07)			
Unmulesed	2.64 (0.01)	2.06 (0.01)			2.92 (0.01)	18.85 (0.03)			
Sex	***	***	***	***	***	**	***	***	ns
Female	2.63 (0.01)	2.06 0.01)	78.9 (0.1)	15.72 (0.02)	2.96 (0.01)	18.89 (0.04)	103.7 (0.2)	79.9 (0.3)	
Male	2.62 (0.01)	2.04 (0.01)	78.5 (0.1)	15.28 (0.02)	2.85 (0.01)	18.74 (0.04)	105.8 (0.2)	75.9 (0.3)	
Birth rearing type	***	***	***	***	ns	***	ns	***	ns
SS	2.78 (0.01)	2.18 (0.01)	79.2 (0.1)	15.45 (0.02)		18.90 (0.04)		77.7 (0.2)	
MS	2.57 (0.02)	2.00 (0.02)	78.4 (0.2)	15.67 (0.05)		18.56 (0.11)		76.8 (0.7)	
MM	2.37 (0.01)	1.83 (0.01)	77.9 (0.1)	15.56 (0.02)		18.74 (0.06)		79.1 (0.5)	
Age of dam	***	***	ns	***	***	ns	ns	***	ns
Maiden	2.54 (0.02)	1.98 (0.01)		15.48 (0.03)	2.87 (0.01)			77.4 (0.5)	
Adult	2.66 (0.01)	2.08 (0.01)		15.51 (0.01)	2.92 (0.01)			78.0 (0.2)	
Management group	***	***	***	***	***	***	***	***	***
AGE	***	***	ns	***	***	***	ns	***	ns
yWT	***	***	ns	***	***	***	ns	***	**
Significant interactions	Line.Brtype* Sex.Mgp*** Brtype.Dage* Brtype.Mgp**	Sex.Dage* Sex.Mgp*** Brtype.Mgp** Dage.Mgp*	Line.Sex ** Line.Brtype** Sex.Mgp***	Line.Brtype** Line.Mgp* Sex.Mgp*** Brtype.Dage*	Line.Brtype*** Line.Mgp*** Mules.Mgp** Sex.Mgp***	Line.Brtype* Mules.Mgp** Sex.Mgp** Dage.Mgp*	Dage.Mgp*	Line.Sex *** Mules.Sex** Sex.Brtype* Sex.Mgp***	

Line = selection line, Brtype = birth-rearing type, Dage = age of dam, Mgp = management group, yWT = yearling bodyweight, SS = born and reared single, MS = born multiple and reared single, MM = born and reared multiple; *** P<0.001, ** P<0.01, * P<0.05, ns not significant

5.2.4 Genetic parameter estimates

Breech strike. Breech strike had low to moderate heritability, moderate phenotypic correlation across ages, and moderate to very high genetic correlation across ages (Table 14.). These genetic correlations indicate that animals selected at young age (weaners or yearlings) are likely to also exhibit resistance as adults. Hence, there is value to commercial sheep producers in culling young animals that become breech struck, if they would otherwise enter the breeding flock.

Table 14. Phenotypic variance (Vp), heritability (bold, diagonal), phenotypic correlations (above diagonal) and genetic correlations (below diagonal) for breech strike recorded at weaner (w), yearling (y) and adult (a) ages. Shaded cells show correlations of particular interest.

Trait	Vp	wBRSTR	yBRSTR	aBRSTR
wBRSTR	0.21 (0.01)	**0.18 (0.03)**	0.29 (0.02)	0.22 (0.03)
yBRSTR	0.09 (0.00)	0.92 (0.07)	**0.16 (0.03)**	0.33 (0.02)
aBRSTR	0.61 (0.02)	0.40 (0.13)	0.26 (0.14)	**0.26 (0.05)**

The yearling breech strike trait reported in Table 14 includes data from both males and females. An additional breech strike trait, combined yearling and adult female breech strike (y-aBRSTR), was used to estimate correlations between adult breech strike and younger-age indicator traits, and between adult breech strike and adult production traits, had $h^2 =$ 0.27 (0.05).

Indirect selection criteria. NWR, BWR and BRWR, as well as BCOV and CCOV were recorded at birth, marking, post-weaning and yearling ages. DAG and URINE were only routinely recorded at post-weaning when expression was usually greatest, so there are no across-age correlations for these traits.

For all ages up to and including yearlings, all five of the repeat-measured traits had moderate heritability (h^2) and had at least moderate genetic correlation (r_g) across the ages (Tables 15, 16 17, 18, and 19). The genetic correlations tended to be highest at adjacent ages. These heritability and genetic correlation estimates are conducive to genetic improvement in any of these traits, recorded at any point up to and including yearling age. Of these traits, BCOV tended to have the lowest heritability, and BRWR the highest correlation across ages, suggesting that it is highly repeatable across ages.

Table 15. Phenotypic variance (Vp), heritability (bold, diagonal), phenotypic correlations (above diagonal) and genetic correlations (below diagonal) for neck wrinkle (NWR) at birth (b), marking (m), post-weaning (p) and yearling (y) age, s.e's in parentheses.

Trait	Vp	bNWR	mNWR	pNWR	yNWR
bNWR	0.49 (0.02)	**0.42 (0.07)**	0.31 (0.02)	0.18 (0.03)	0.16 (0.03)
mNWR	0.55 (0.02)	0.69 (0.08)	**0.43 (0.04)**	0.36 (0.02)	0.35 (0.02)
pNWR	0.53 (0.01)	0.40 (0.11)	0.74 (0.07)	**0.26 (0.04)**	0.42 (0.02)
yNWR	0.51 (0.01)	0.37 (0.10)	0.58 (0.06)	0.83 (0.05)	**0.36 (0.04)**

Table 16. Phenotypic variance (Vp), heritability (bold, diagonal), phenotypic correlations (above diagonal) and genetic correlations (below diagonal) for body wrinkle (BWR) at birth (b), marking (m), post-weaning (p) and yearling (y) age, s.e's in parentheses.

Trait	Vp	bBWR	mBWR	pBWR	yBWR
bBWR	0.57 (0.02)	**0.25 (0.05)**	0.32 (0.02)	0.14 (0.03)	0.21 (0.02)
mBWR	0.62 (0.02)	0.76 (0.09)	**0.35 (0.03)**	0.34 (0.02)	0.35 (0.02)
pBWR	0.41 (0.01)	0.37 (0.14)	0.77 (0.07)	**0.18 (0.03)**	0.31 (0.02)
yBWR	0.55 (0.01)	0.52 (0.12)	0.66 (0.06)	0.73 (0.08)	**0.28 (0.03)**

Table 17. Phenotypic variance (Vp), heritability (bold, diagonal), phenotypic correlations (above diagonal) and genetic correlations (below diagonal) for breech wrinkle (BRWR) at birth (b), marking (m), post-weaning (p) and yearling (y) age, s.e's in parentheses.

Trait	Vp	bBRWR	mBRWR	pBRWR	yBRWR
bBRWR	0.71 (0.03)	**0.34 (0.06)**	0.34 (0.02)	0.17 (0.03)	0.20 (0.02)
mBRWR	0.72 (0.02)	0.58 (0.09)	**0.42 (0.04)**	0.37 (0.02)	0.33 (0.02)
pBRWR	0.63 (0.02)	0.46 (0.10)	0.66 (0.05)	**0.31 (0.03)**	0.47 (0.01)
yBRWR	0.57 (0.01)	0.40 (0.10)	0.51 (0.06)	0.89 (0.04)	**0.31 (0.03)**

Table 18. Phenotypic variance (Vp), heritability (bold, diagonal), phenotypic correlations (above diagonal) and genetic correlations (below diagonal) for crutch cover (CCOV) at birth (b), marking (m), post-weaning (p) and yearling (y) age, s.e's in parentheses.

Trait	Vp	bCCOV	mCCOV	pCCOV	yCCOV
bCCOV	0.45 (0.02)	**0.36 (0.06)**	0.17 (0.03)	0.08 (0.03)	0.12 (0.03)
mCCOV	0.42 (0.01)	0.34 (0.10)	**0.35 (0.03)**	0.31 (0.02)	0.29 (0.02)
pCCOV	0.36 (0.01)	0.29 (0.10)	0.71 (0.05)	**0.44 (0.03)**	0.38 (0.02)
yCCOV	0.29 (0.01)	0.29 (0.13)	0.68 (0.08)	0.83 (0.07)	**0.29 (0.05)**

Table 19. Phenotypic variance (Vp), heritability (bold, diagonal), phenotypic correlations (above diagonal) and genetic correlations (below diagonal) for breech cover (BCOV) at birth (b), marking (m), post-weaning (p) and yearling (y) age, s.e's in parentheses.

Trait	Vp	bBCOV	mBCOV	pBCOV	yBCOV
bBCOV	0.28 (0.01)	**0.15 (0.04)**	0.21 (0.03)	0.24 (0.03)	0.18 (0.03)
mBCOV	0.34 (0.01)	0.68 (0.15)	**0.20 (0.03)**	0.27 (0.02)	0.27 (0.02)
pBCOV	0.45 (0.01)	0.87 (0.11)	0.80 (0.07)	**0.29 (0.03)**	0.38 (0.02)
yBCOV	0.41 (0.01)	0.57 (0.15)	0.82 ().07)	0.83 (0.06)	**0.25 (0.03)**

Within ages, NWR, BWR and BRWR were highly correlated genetically (birth, 0.82 (0.06) – 0.91 (0.04); marking 0.91 (0.02) – 0.93 (0.02); post weaning 0.66 (0.08) – 0.82 (0.08); yearling 0.79 (0.05) – 0.89 (0.05) (Tables 20, 21, 22 and 23). For commercial application where it might be simpler to select on neck or body wrinkle, or for phenotypic selection in flocks that have already been mulesed, neck or body wrinkle could be effective alternatives to BRWR because the three traits are so closely associated. Wrinkle traits at young ages are also well correlated with adult wrinkle, but wrinkle of adult ewes is affected by reproductive status at the time of recording (data not reported here). Of the four ages examined, the post-weaning wrinkle traits had lowest genetic correlations and this coincided with the period when their wool length was the longest and this may have impacted the accuracy of wrinkle scoring.

Compared to the wrinkle traits, genetic correlations between BCOV and CCOV were consistently lower and more variable at the different ages (birth, 0.43 (0.13); marking, 0.46 (0.09); post weaning, 0.15 (0.08); yearling, 0.69 (0.09). There is some evidence that wool cover traits tend to change from young sheep to adults and with physiological status. For example, ewes tended toward lower BCOV and CCOV as they aged; and within-years, lactating ewes tended to be barer than non-pregnant ewes or those that had lambed but the lamb died (i.e. the ewe did not maintain a lactation). At all ages, the wool cover traits were poorly correlated with the wrinkle traits (most were less than 0.15), so it cannot be said that plain animals (low wrinkle) also tend to be barer.

At marking, post-weaning and yearling ages measured BW and BD were well correlated with BCOV (BCOV x BW r_p -0.37 – -0.57, r_g -0.86 – -0.90; BCOV x BD r_p -0.44 – -0.64, r_g -0.80 – -0.94). This indicates that visual assessment of BCOV is an effective method of recording bare area on the breech.

BRWR was consistently correlated genetically with wBRSTR (birth 0.47 (0.14); marking 0.26 (0.10); post weaning 0.62 (0.09); yearling 0.33 (0.11)). Genetic correlations between BCOV and wBRSTR were also usually at least moderate (birth 0.59 (0.18); marking 0.09 (0.13); post-weaning 0.35 (0.11); yearling 0.36 (0.12). For both pairs of traits the correlation was lowest at marking age, suggesting that for selection purposes, delaying breech wrinkle scoring to post-weaning may be more accurate than at marking.

pDAG was not closely correlated genetically with either BRWR (0.16 (0.11)) or BCOV (0.11 (0.12)) but had very high genetic correlation with wBRSTR (0.81 (0.09)). This indicates that sheep that are genetically predisposed to dag are also genetically predisposed to breech strike. Perhaps this association is somehow odour related? pURINE was phenotypically correlated with wBRSTR (0.18 (0.03)), but the genetic correlation was negligible (0.06 (0.16). In this population pDAG and pURINE had low heritability (0.16 (0.03) and 0.22 (0.05) respectively), which is similar to breech strike itself.

Despite the very high genetic correlation between pDAG and wBRSTR, and the phenotypic correlation between pURINE and wBRSTR, neither are regarded to be particularly good candidates as indirect selection criteria for breech strike in this particular environment. Here, DAG is a 'transient' trait – when it does occur, it is most often in young sheep, and can be attributable to any one of several causes. DAG in adult sheep is not usually a problem.

In this environment animals that get daggy or are particularly urine stained should be culled because if they have wet dag or severe stain during a fly challenge, they will almost certainly get fly struck. However, due to the other parameters (phenotypic variance and heritability) being relatively unfavourable for indirect selection, and in the case of dag, the erratic expression, dag and urine stain should be used as an opportunistic independent culling tool as necessary, rather than as a routine selection criterion. That is, from a phenotypic perspective there is value in culling individual animals that are particularly problematic in terms of dag or urine stain, but to build a formal flystrike resistance selection program around DAG in the summer rainfall environment is unlikely to be successful, and perhaps even a waste of potential selection emphasis.

These results are in contrast, to the WA flock in the period when the experimental protocol involved delayed crutching. That is, dag had suitable phenotypic variance, heritability and correlation with breech strike to make it a suitable indirect selection criterion for breech strike (Greeff and Karlsson 2009; Greeff *et al.* 2014). However, in the later phase of the WA study when crutching was conducted at a more usual time in the production calendar (immediately prior to fly season), breech wrinkle then superseded dag as an indirect selection criterion (J.J. Greeff, unpublished data).

Table 24 shows the phenotypic and genetic parameters for y-aBRSTR among females only. The genetic correlations between y-aBRSTR and the key indicator traits generally reflected those for wBRSTR, with the exception of yCCOV (which was low). Interestingly, even though adult sheep rarely exhibit dag in this environment, and there is no phenotypic correlation between y-aBRSTR and pDAG, there remains a moderate genetic correlation between y-aBRSTR and pDAG. For pURINE, the phenotypic correlation with y-aBRSTR was stronger than for wBRSTR, suggesting that ewes that are urine stained as youngsters remain so into adulthood. There was negligible genetic correlation between pURINE and wBRSTR, but there was a moderate genetic correlation between pURINE and y-aBRSTR, which as with dag, may also be somehow associated with the sheep's odour.

Table 20. Phenotypic variance (Vp), heritability (bold, diagonal), phenotypic correlations (above diagonal) and genetic correlations (below diagonal) for wrinkle and wool cover traits recorded at birth (b), and weaner (w) breech strike, s.e.'s in parentheses. Shaded cells show correlations of particular interest.

Trait	Vp	bNWR	bBWR	bBRWR	bCCOV	bBCOV	wBRSTR
bNWR	0.49 (0.02)	**0.42 (0.06)**	0.65 (0.02)	0.56 (0.02)	-0.02 (0.03)	0.06 (0.06)	0.05 (0.03)
bBWR	0.58 (0.02)	0.91 (0.04)	**0.36 (0.06)**	0.66 (0.02)	-0.03 (0.03)	0.04 (0.03)	0.07 (0.03)
bBRWR	0.72 (0.02)	0.82 (0.06)	0.90 (0.4)	**0.37 (0.06)**	-0.05 (0.03)	0.02 (0.03)	0.08 (0.03)
bCCOV	0.45 (0.02)	0.04 (0.14)	-0.03 (0.13)	-0.12 (0.13)	**0.38 (0.06)**	0.20 (0.03)	0.01 (0.03)
bBCOV	0.29 (0.02)	0.28 (0.17)	0.26 (0.16)	0.11 (0.17)	0.43 (0.15)	**0.22 (0.06)**	0.03 (0.03)
wBRSTR	0.21 (0.01)	0.42 (0.15)	0.41 (0.15)	0.47 (0.14)	0.27 (0.14)	0.59 (0.18)	**0.18 (0.03)**

Table 21. Phenotypic variance (*Vp*), heritability (bold, diagonal), phenotypic correlations (above diagonal) and genetic correlations (below diagonal) for wrinkle and wool cover traits recorded at marking (m), and weaner (w) breech strike, s.e.'s in parentheses. Shaded cells show correlations of particular interest.

Trait	V_p	mNWR	mBWR	mBRWR	mCCOV	mBCOV	mBW	mBD	TL	wBRSTR
mNWR	0.54 (0.02)	**0.39 (0.04)**	0.71 (0.01)	0.67 (0.01)	0.06 (0.02)	0.02 (0.02)	0.00 (0.02)	0.00 (0.02)	0.09 (0.02)	0.09 (0.02)
mBWR	0.63 (0.02)	0.93 (0.02)	**0.36 (0.03)**	0.72 (0.01)	0.06 (0.02)	0.02 (0.02)	-0.01 (0.02)	-0.01 (0.02)	0.04 (0.02)	0.10 (0.02)
mBRWR	0.73 (0.02)	0.93 (0.02)	0.91 (0.02)	**0.43 (0.04)**	0.05 (0.02)	0.02 (0.02)	0.01 (0.02)	-0.01 (0.02)	0.05 (0.02)	0.10 (0.02)
mCCOV	0.42 (0.01)	0.04 (0.08)	0.08 (0.08)	0.04 (0.08)	**0.35 (0.03)**	0.20 (0.02)	-0.14 (0.02)	-0.17 (0.02)	-0.10 (0.02)	0.06 (0.02)
mBCOV	0.34 (0.01)	-0.03 (0.1)	0.09 (0.1)	-0.04 (0.1)	0.46 (0.09)	**0.20 (0.03)**	-0.37 (0.02)	-0.44 (0.02)	-0.12 (0.02)	0.03 (0.02)
mBW	53.4 (1.5)	-0.12 (0.1)	-0.13 (0.1)	-0.02 (0.10)	-0.44 (0.09)	-0.86 (0.06)	**0.23 (0.04)**	0.31 (0.02)	0.16 (0.02)	-0.06 (0.02)
mBD	146.0 (4.3)	-0.05 (0.1)	-0.16 (0.1)	-0.03 (0.09)	-0.51 (0.08)	-0.80 (0.06)	0.52 (0.10)	**0.25 (0.04)**	0.17 (0.02)	-0.00 (0.02)
TL	601.5 (22.4)	0.08 (0.07)	0.03 (0.07)	0.02 (0.07)	-0.25 (0.07)	-0.37 (0.09)	0.41 (0.09)	0.32 (0.09)	**0.62 (0.04)**	0.03 (0.02)
wBRSTR	0.21 (0.01)	0.13 (0.11)	0.23 (0.1)	0.26 (0.10)	0.20 (0.11)	0.09 (0.13)	-0.08 (0.13)	-0.25 (0.13)	0.12 (0.10)	**0.18 (0.03)**

Table 22. Phenotypic variance (Vp), heritability (bold, diagonal), phenotypic correlations (above diagonal) and genetic correlations (below diagonal) for wrinkle and wool cover traits recorded at post-weaning (p), and weaner (w) breech strike, s.e.'s in parentheses. Shaded cells show correlations of particular interest.

Trait	Vp	pNWR	pBWR	pBRWR	pCCOV	pBCOV	pBW	pBD	pDAG	pURINE	wBRSTR
pNWR	0.53 (0.01)	**0.24 (0.04)**	0.54 (0.01)	0.38 (0.02)	0.08 (0.02)	0.01 (0.02)	0.00 (0.02)	0.01 (0.02)	0.01 (0.02)	0.09 (0.03)	0.07 (0.02)
pBWR	0.41 (0.01)	0.82 (0.07)	**0.17 (0.03)**	0.41 (0.02)	0.09 (0.02)	0.02 (0.02)	-0.03 (0.02)	-0.02 (0.02)	0.02 (0.02)	0.13 (0.03)	0.08 (0.02)
pBRWR	0.63 (0.02)	0.66 (0.08)	0.75 (0.08)	**0.30 (0.03)**	0.12 (0.02)	0.05 (0.02)	-0.03 (0.02)	-0.01 (0.02)	0.05 (0.02)	0.17 (0.03)	0.20 (0.02)
pCCOV	0.36 (0.01)	-0.01 (0.09)	0.04 (0.10)	0.15 (0.08)	**0.43 (0.04)**	0.29 (0.02)	-0.24 (0.02)	-0.24 (0.02)	0.03 (0.02)	0.08 (0.03)	0.09 (0.02)
pBCOV	0.46 (0.01)	-0.09 (0.10)	0.10 0.11)	0.10 (0.09)	0.60 (0.06)	**0.30 (0.03)**	-0.54 (0.01)	-0.64 (0.01)	-0.01 (0.02)	0.02 (0.03)	0.03 (0.02)
pBW	87.4 (2.2)	0.05 (0.10)	-0.17 (0.11)	-0.13 (0.09)	-0.55 (0.06)	-0.90 (0.04)	**0.28(0.03)**	0.43 (0.01)	0.02 (0.02)	-0.03 (0.03)	-0.03 (0.02)
pBD	147.7 (4.0)	0.06 (0.10)	-0.11 (0.11)	-0.11 (0.09)	-0.50 (0.06)	-0.94 (0.03)	0.81 (0.05)	**0.30 (0.03)**	-0.01 (0.02)	0.01 (0.03)	0.02 (0.02)
pDAG	0.37 (0.01)	-0.12 (0.14)	0.08 (0.14)	0.16 (0.11)	0.19 (0.10)	0.11 (0.12)	0.04 (0.12)	-0.18 (0.11)	**0.16 (0.03)**	0.05 (0.03)	0.24 (0.02)
pURINE	0.39 (0.02)	0.25 (0.16)	0.16 (0.16)	0.29 (0.12)	0.15 (0.12)	0.35 (0.12)	-0.26 (0.13)	-0.25 (0.13)	0.28 (0.16)	**0.22 (0.05)**	0.18 (0.03)
wBRSTR	0.21 (0.01)	0.35 (0.13)	0.39 (0.13)	0.62 (0.09)	0.32 (0.10)	0.35 (0.11)	-0.35 (0.10)	-0.34 (0.10)	0.81 (0.09)	0.06 (0.16)	**0.18 (0.03)**

Table 23. Phenotypic variance (Vp), heritability (bold, diagonal), phenotypic correlations (above diagonal) and genetic correlations (below diagonal) for wrinkle and wool cover traits recorded at yearling age (y), and weaner breech strike (wBRSTR), s.e.'s in parentheses. Shaded cells show correlations of particular interest.

Trait	Vp	yNWR	yBWR	yBRWR	yCCOV	yBCOV	yBW	yBD	yFACE	wBRSTR
yNWR	0.51 (0.01)	**0.33 (0.04)**	0.61 (0.01)	0.50 (0.01)	0.06 (0.02)	0.05 (0.02)	-0.06 (0.02)	0.03 (0.02)	0.12 (0.02)	0.11 (0.02)
yBWR	0.55 (0.01)	0.89 (0.03)	**0.28 (0.03)**	0.53 (0.01)	0.10 (0.02)	0.04 (0.02)	-0.07 (0.02)	0.01 (0.02)	0.10 (0.02)	0.11 (0.02)
yBRWR	0.58 (0.02)	0.82 (0.04)	0.79 (0.05)	**0.33 (0.03)**	0.07 (0.02)	0.06 (0.02)	-0.06 (0.02)	0.01 (0.02)	0.12 (0.02)	0.16 (0.02)
yCCOV	0.29 (0.01)	-0.08 (0.10)	0.01 (0.11)	-0.10 (0.10)	**0.33 (0.05)**	0.25 (0.02)	-0.26 (0.02)	-0.12 (0.02)	0.11 (0.02	0.08 (0.03)
yBCOV	0.41 (0.01)	0.13 (0.1)	0.16 (0.10)	0.11 (0.10)	0.69 (0.09)	**0.24 (0.03)**	-0.57 (0.02)	-0.62 (0.02)	0.11 (0.02)	0.04 (0.02)
yBW	104.6 (4.0)	-0.04 (0.12)	-0.13 (0.12)	0.02 (0.11)	-0.69 (0.11)	-0.86 (0.06)	**0.21 (0.04)**	0.25 (0.02)	-0.12 (0.02)	0.00 (0.03)
yBD	108.0 (4.2)	-0.13 90.12)	-0.17 (0.13)	-0.08 (0.12)	-0.77 (0.11)	-0.93 (0.07)	0.80 (0.10)	**0.20 (0.04)**	-0.12 (0.02)	-0.01 (0.03)
yFACE	0.56 (0.02)	0.27 (0.07)	0.23 (0.08)	0.32 (0.07)	0.22 (0.09)	0.22 (0.09)	-0.41 (0.10)	-0.31 (0.11)	**0.54 (0.04)**	0.07 (0.02)
wBRSTR	0.21 (0.01)	0.37 (0.10)	0.38 (0.11)	0.33 (0.11)	0.31 (0.13)	0.36 (0.12)	-0.25 (0.15)	-0.25 (0.16)	0.23 (0.10)	**0.18 (0.03)**

Table 24. Phenotypic variance (V_p), heritability (h^2), Phenotypic (r_p) and genetic correlations (r_g) between key yearling wrinkle and wool cover traits, and combined yearling-adult breech strike (y-aBRSTR), among females only, s.e.'s in parentheses.

			y-aBRSTR	
Trait	***Vp***	h^2	r_p	r_g
yBRWR	0.57	0.37 (0.05)	0.23 (0.05)	0.39 (0.11)
yBCOV	0.36	0.30 (0.05)	0.10 (0.05)	0.36 (0.13)
yCCOV	0.34	0.45 (0.06)	0.11 (0.05)	0.08 (0.12)
pDAG	0.34	0.15 (0.04)	0.05 (0.05)	0.49 (0.16)
pURINE	0.39	0.22 (0.05)	0.27 (0.05)	0.48 (0.14)

Production traits

Yearlings.

Relationships between breech strike and indicator traits, and economically important production traits were estimated to aid prediction of response to selection in a multi-trait breeding objective (Table 25). Breech strike itself was either neutral, or favourably correlated with bodyweight and important fleece traits except for FD, for which there was a moderate negative genetic correlation (-0.25 (0.08)). Among the breech strike indirect selection criteria examined, there were neutral or favourable genetic correlations for all of the production traits examined except BRWR x GFW (0.36 (0.07)), BRWR x CFW (0.27 (0.08)), BCOV x FD (-0.14 (0.07)), and DAG x FD (-0.22 (0.09)).

Although there are some antagonistic relationships between breech traits and production traits, they are not so strong as to preclude concurrent genetic gain. Further, there are favourable genetic relationships between breech traits and production traits, particularly those involving bodyweight and CVD that are advantageous in multi-trait breeding programs.

Adults.

To this point the focus in this report has been on young-age traits. The majority of breech strike records exist for younger animals, which enables most precise estimation of genetic parameters. Further, in commercial breeding programs, indirect selection criteria that can be measured at a young age and indicate performance in the breeding objective trait either at that time or in adulthood are desired. Even so, the relationships between breech traits and adult production traits remain important for prediction of lifetime impact on productivity of selection for breech strike resistance on.

Older age (hogget and adult) traits including breech strike, breech strike indicators, production traits, and reproduction performance were recorded in this flock. A combined yearling-adult breech strike trait was developed and evaluated against two-year old fleece traits using females only, since few males were retained past 1.5 years of age, and the breech strike rate among males were lower than females (Table 26).

A cursory evaluation of genetic parameters involving adult traits is reported here to gauge similarities with the young-age traits. However, due to the smaller number of records; complications of repeated reproduction events (more fixed effects classes); and variable number of years that ewes were retained in the flock and thus have breech strike records, inevitably there are higher errors on any genetic parameters estimated. Nevertheless, associations between y-aBRSTR and key yearling breech strike indicators (yBRWR, yBCOV and yCCOV, pDAG and pURINE), and between those traits and adult (a2) production traits are examined.

In general, the correlations between y-aBRSTR and adult fleece traits reflect those for wBRSTR and yearling fleece traits, and there are no new causes for concern with respect to breeding program design. There are four main points of difference between the two sets of genetic parameters. Firstly, the genetic correlation between y-aBRSTR and a2FD is weaker than for yFD (-0.05 *versus* -0.25); the genetic correlation between yBRWR and a2FD is stronger than for yFD (-0.23 *versus* -0.06); the genetic correlation between yCCOV and yCVD is of opposite sign to that between yCCOV and a2CVD (+0.27 *versus* -0.18); and the genetic correlations between pURINE and fleece weight (greasy and clean) are weaker than those between pURINE and a2GFW or a2CFW (GFW, 0.13 *versus* 0.30; CFW 0.03 *versus* 0.27).

Table 25. Phenotypic variance (V_p) and heritability (h^2) for production traits, and Phenotypic (r_p) and genetic (r_g) correlations between production traits and breech strike and its indirect selection criteria.

			BRWR x		BCOV x		CCOV x		DAG x		URINE x		wBRSTR	
	V_p	h^2	r_p	r_g	r_p	r_g	r_p	r_g	r_p	r_g	r_p	r_g	r_p	r_g
wWT	10.51	0.58 (0.05)	-0.02	-0.23 (0.08)	-0.14	-0.36 (0.08)	-0.20	-0.54 (0.06)	-0.16	-0.37 (0.10)	0.00	-0.15 (0.14)	-0.09	-0.18 (0.11)
yWT	18.97	0.46 (0.04)	-0.11	-0.25 (0.08)	-0.18	-0.42 (0.07)	-0.16	-0.42 (0.07)	-0.07	-0.23 (0.10)	-0.04	-0.11 (0.13)	-0.04	-0.08 (0.10)
yGFW	0.13	0.45 (0.04)	0.28	0.36 (0.07)	0.04	0.11 (0.08)	0.10	0.10 (0.07)	-0.07	-0.21 (0.10)	0.11	0.13 (0.12)	0.04	0.08 (0.10)
yCFW	0.09	0.43 (0.04)	0.24	0.27 (0.08)	0.03	0.11 (0.08)	0.09	0.11 (0.07)	-0.06	-0.20 (0.10)	0.07	0.03 (0.12)	0.03	0.03 (0.10)
yYLD	13.36	0.59 (0.03)	-0.05	-0.18 (0.07)	0.00	-0.02 (0.07)	0.00	0.00 (0.06)	0.01	-0.02 (0.09)	-0.10	-0.27 (0.11)	-0.01	-0.12 (0.09)
yFD	0.84	0.72 (0.03)	-0.04	-0.06 (0.07)	-0.05	-0.14 (0.07)	-0.11	-0.17 (0.06)	-0.06	-0.22 (0.09)	0.00	0.04 (0.11)	-0.08	-0.25 (0.08)
ySDFD	0.11	0.56 (0.03)	0.15	0.32 (0.07)	0.00	-0.01 (0.07)	0.06	0.17 (0.06)	0.01	0.15 (0.10)	0.12	0.36 (0.11)	0.05	0.12 (0.10)
yCVD	4.20	0.58 (0.03)	0.18	0.37 (0.07)	0.03	0.07 (0.07)	0.12	0.27 (0.06)	0.06	0.30 (0.10)	0.12	0.35 (0.11)	0.11	0.31 (0.09)
yCURV	97.24	0.60 (0.03)	0.00	0.00 (0.07)	0.00	-0.06 (0.07)	-0.01	-0.03 (0.06)	0.00	0.05 (0.09)	-0.03	-0.15 (0.11)	-0.01	0.05 (0.09)
ySL	90.13	0.54 (0.04)	-0.17	-0.36 (0.08)	0.03	0.17 (0.08)	-0.03	0.07 (0.07)	-0.01	0.03 (0.11)	-0.01	0.20 (0.14)	-0.06	-0.16 (0.11)
ySS	65.78	0.30 (0.04)	-0.02	-0.08 (0.11)	0.02	0.05 (0.11)	-0.04	-0.07 (0.10)	-0.08	-0.22 (0.14)	-0.05	-0.28 (0.17)	-0.13	-0.17 (0.14)
yCOL	0.36	0.38 (0.04)	0.03	0.15 (0.08)	-0.01	-0.06 (0.09)	0.01	-0.07 (0.08)	-0.02	-0.19 (0.11)	0.06	0.13 (0.13)	0.00	0.01 (0.11)
yCRIMP	0.46	0.33 (0.03)	0.05	0.03 (0.09)	0.04	0.02 (0.09)	0.06	0.06 (0.08)	0.00	-0.10 (0.11)	0.08	0.28 (0.13)	0.03	-0.11 (0.11)
yFLROT	0.00	0.24 (0.03)	0.10	0.11 (0.10)	0.01	-0.05 (0.11)	0.02	-0.03 (0.09)	0.01	-0.03 (0.13)	0.04	-0.18 (0.15)	0.02	0.07 (0.12)
pWEC	0.40	0.13 (0.03)	0.00	0.12 (0.13)	-0.04	0.07 (0.13)	0.00	0.10 (0.12)	0.03	0.13 (0.16)	0.04	-0.07 (0.18)	-0.02	-0.07 (0.15)

All s.e. on r_p = 0.02 except for URINE which were 0.03

Dark shaded cells indicate favourable correlations and light shaded cells indicate unfavourable correlations

Table 26. Phenotypic variance (Vp), heritability (bold, diagonal), phenotypic correlations (above diagonal) and genetic correlations (below diagonal) for key yearling wrinkle and wool cover traits recorded, yearling-adult breech strike (y-aBRSTR), and two-year old adult (a2) fleece traits for females only, s.e.'s in parentheses.

			y-aBRSTR		yBRWR		yBCOV		yCCOV		pDAG		pURINE	
	Vp	**h^2**	**r_p**	**r_g**	**r_p**	**r_g**	**r_p**	**r_g**	**r_p**	**r_g**	**r_p**	**r_g**	**r_p**	**r_g**
a2COL	0.50	0.39 (0.08)	0.04	0.01 (0.16)	-0.04	-0.02 (0.14)	0.00	0.01 (0.16)	-0.04	-0.08 (0.15)	0.00	-0.26 (0.18)	0.05	0.17 (0.18)
a2CRIMP	0.54	0.35 (0.07)	0.05	0.01 (0.16)	0.11	0.15 (0.14)	-0.05	-0.24 (0.15)	0.01	-0.10 (0.15)	0.00	-0.28 (0.18)	0.02	0.04 (0.19)
a2GFW	0.22	0.81 (0.04)	0.16	0.20 (0.09)	0.28	0.40 (0.07)	-0.03	0.06 (0.09)	-0.07	-0.20 (0.08)	-0.02	-0.18 (0.12)	0.14	0.30 (0.11)
a2CFW	0.15	0.77 (0.05)	0.15	0.21 (0.09)	0.26	0.38 (0.08)	-0.02	0.11 (0.09)	-0.07	-0.17 (0.08)	-0.03	-0.19 (0.12)	0.11	0.27 (0.12)
a2YLD	13.30	0.76 (0.05)	-0.02	-0.02 (0.09)	-0.04	-0.09 (0.08)	0.02	0.13 (0.09)	0.02	0.06 (0.09)	-0.02	-0.01 (0.12)	-0.09	-0.19 (0.12)
a2FD	1.31	0.85 (0.04)	-0.01	-0.05 (0.09)	-0.10	-0.23 (0.08)	-0.11	-0.26 (0.09)	-0.14	-0.22 (0.08)	-0.02	-0.32 (0.12)	0.02	0.02 (0.12)
a2SDFD	0.12	0.74 (0.05)	0.10	0.15 (0.09)	0.14	0.17 (0.08)	-0.03	0.00 (0.09)	-0.09	-0.28 (0.08)	0.00	0.01 (0.13)	0.13	0.31 (0.12)
a2CVD	3.07	0.54 (0.05)	0.13	0.24 (0.10)	0.21	0.36 (0.09)	0.03	0.17 (0.17)	0.00	-0.18 (0.10)	0.02	0.25 (0.14)	0.12	0.38 (0.13)
a2CURV	115	0.71 (0.05)	-0.01	0.03 (0.10)	0.01	0.06 (0.08)	0.06	0.11 (0.09)	0.11	0.22 (0.09)	0.03	0.12 (0.13)	-0.08	-0.08 (0.12)
a2sl	80.84	0.53 (0.10)	0.03	0.23 (0.15)	-0.08	-0.15 (0.13)	-0.02	0.22 (0.16)	0.04	0.25 (0.14)	0.05	0.34 (0.17)	0.07	0.54 (0.16)
a2ss	48.04	0.20 (0.09)	-0.05	-0.22 (0.26)	-0.03	-0.34 (0.26)	-0.06	-0.05 (0.28)	-0.03	-0.13 (0.27)	-0.03	0.02 (0.27)	0.00	-0.37 (0.27)

s.e. on phenotypic correlations ranged from 0.03 to 0.05.

Dark shaded cells indicate favourable correlations and light shaded cells indicate unfavourable correlations

5.2.5 Genetic trends

Figure 12. shows genetic trends for the Intense/Resistant and Control/Susceptible lines for weaner breech strike and the three key indirect selection criteria, BRWR, BCOV and DAG. These genetic trends closely reflect the phenotypic trends (Figures 4, 5, 6, and 7). The trend for wBRSTR is quite erratic compared to the other traits, and this is thought to be due to the nature of the trait in that it is almost binomial, and expression is greatly affected by environment. For example, the Control/Susceptible lines were most divergent from the Intense/Resistant lines in 2006 and 2014. Those years were moderate to high challenge years and some of the sires used were extremely susceptible, with almost all progeny in some groups becoming fly struck. Conversely, the selection lines came together in 2008 and 2013. Possible reasons for these anomalies are described as follows.

In 2008 (Phase I), the comparison to the Intense line was an *unselected* Control (rather than selected to be susceptible). By chance, 3 of the 4 sires used in the Control line that year turned out to be more resistant to breech strike than those chosen from industry for the Intense line. Despite that there were some very susceptible 2006 drop ewes join the breeding flock in 2008, these factors, coupled with a low challenge flystrike season, resulted in no difference in the genetic merit of the Control and Intense selection lines in that year. 2013 was a drought year and the climate was very dry throughout the flystrike season. This resulted in low accuracy of the breech strike phenotyping in that year. Effectively, even though the animals in the Susceptible line may have indeed been quite susceptible, the weather conditions were simply not conducive to flystrike, so even highly susceptible animals did not become struck. The inaccuracy of flystrike phenotyping in that year had flow-on effects to the genetic trend of the Susceptible line. These irregularities observed in the genetic trends over a relatively short period of time in sheep breeding terms, are examples of the vagaries of selective breeding for a disease trait that is heavily impacted by the environment. Notably, the genetic trends for the indirect selection criteria, particularly breech wrinkle are more stable, and the selection lines continued to diverge.

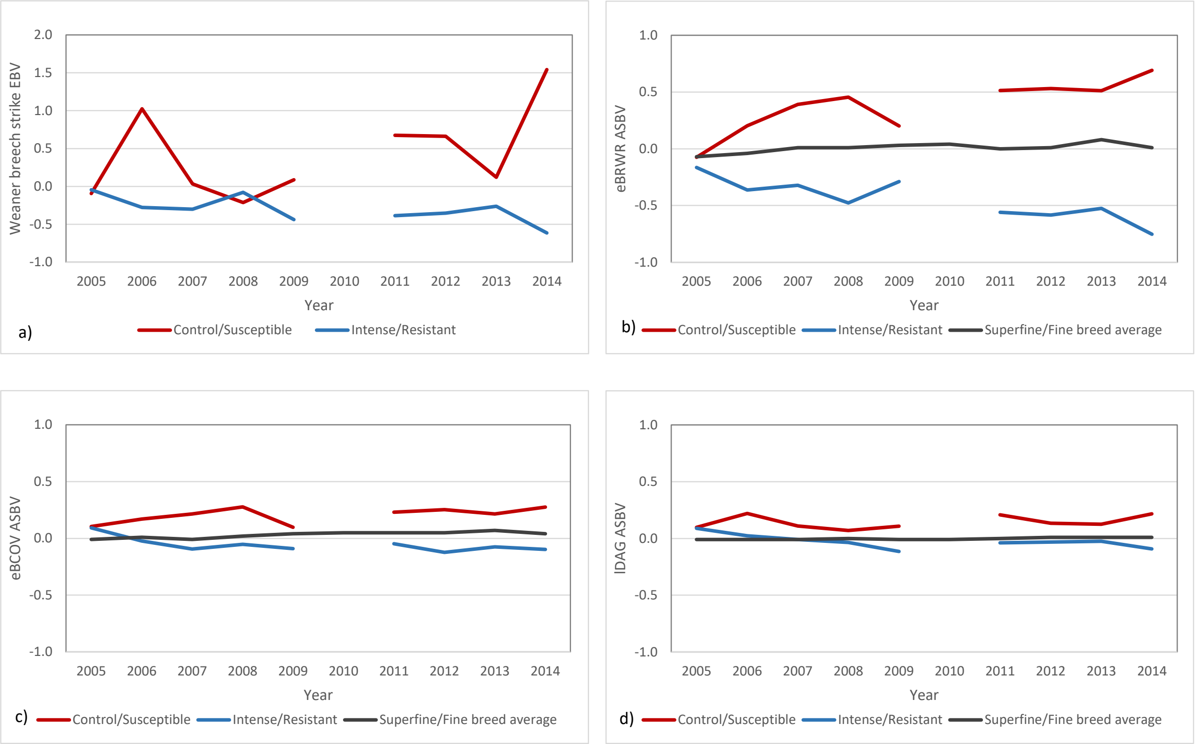

Figure 12. Genetic trends in a) weaner breech strike (within-flock estimated breeding values (EBV)), b) early breech wrinkle Australian Sheep Breeding Values (eBRWR ASBV), c) early breech cover (eBCOV ASBV), and d) late dag (lDAG ASBV) with the Merino Select superfine/Fine wool type average.

5.3 Subjects for further research

Adult breech strike and production traits (a2) have only been examined here in a preliminary manner, however there is no strong evidence for any vastly different scenario to that for weaner breech strike and yearling production traits. Hence, the author does not believe there is a lot to be gained from further genetic analysis of yearling or adult breech strike, and the repeated adult fleece traits. There may be more value in effort toward examination of reproduction records in relation to selection for breech strike resistance.

Reproduction traits were routinely recorded in this flock, including litter size scanned, number of lambs born and number of lambs reared. Selection line differences in reproduction traits were routinely reported in a preliminary way in the annual milestone reports, and there was some evidence of a favourable association between reproduction efficiency and body wrinkle that emerged as a selection line differences. Genetic analysis of reproduction traits in relation to selection for breech strike resistance has not been conducted to date because the author regards that it may not withstand the scrutiny of peer review due to the confounding effect in selection lines and the predominant use of artificial insemination. However, it may be worthwhile to attempt genetic analysis of the reproduction traits for the entire dataset.

[A further small project encompassing genetic analysis (if possible) of the reproduction data of the Armidale flock could be undertaken. Depending upon whether the statistical analysis were simply on a phenotypic level or could include genetic parameter estimation, it is envisaged this could be done over approximately 12 weeks on a part-time basis (due to competing time commitments), at a total cost of $50-55K. Assuming 50% co-investment, the cost to AWI of such a project would be approximately $25-30K.

Given that reproduction rate is a strong driver of economic performance in Merino breeding enterprises, the abovementioned study could incorporate some superficial economic analysis comparing the Resistant and Susceptible selection lines.]

5.4 Summary

Results obtained here indicate that selective breeding is a viable means of improving breech strike resistance in Australian Merino flocks. In this population of fine wool sheep in a summer-dominant rainfall environment, the optimal indirect selection criterion for breech strike was breech wrinkle. Breech wrinkle exhibits variation within populations and is easily assessed in the field at any time when the breech wool is short; is repeatable across ages; is moderately heritable; and highly correlated genetically with breech strike. This field study demonstrated that selection on breech wrinkle as an effective means of genetic improvement of breech strike.

In contrast, evaluation of the WA population where the sheep were quite plain-bodied (low wrinkle) from the beginning, and where dag is a consistently and considerable issue, dag and breech cover were the more important indirect selection criteria. Interestingly though, in the later years of the study period, when the WA sheep were crutched earlier to reduce the impact of dag, breech wrinkle emerged as a more important characteristics (JJ Greeff, *pers. comm.*).

These varying results from the two populations indicate there is no single common method, but individuals intent on pursuing genetic improvement in breech strike resistance, should tailor their breeding program according to their sheep type and production environment. Based on the evidence obtained from these studies, selective breeding could be regarded as a tool in an integrated pest management program for sheep blowfly. The relative importance of that tool to individual sheep producers will likely vary with their attitudes to factors such as preparedness to continue mulesing; perceived risk to sheep and wool markets by continuation of mulesing; farm chemical use and attitude to residue risk; and preparedness to use other management practices to control flystrike, all of which can potentially reduce reliance on mulesing.

5.5 Publication plan

To date, the majority of communication relating to this Project has focussed on industry – R&D Forums, AWI welfare Forums, industry Newsletters, and articles in industry publications such as Beyond the Bale. Now, with completion of phenotyping to yearling age of the 2014 drop progeny, the focus has moved toward scientific publication. A renewed effort is underway to publish a series of manuscripts based on data from the Armidale flock on the phenotypes, genetic parameters, and implications for breeding for breech strike resistance using fine wool sheep in the summer-dominant rainfall environment. The following series of Journal papers are currently in preparation and are intended for submission to Animal Production Science. One further publication on the genetic trends may also be prepared.

Breech strike genetics of Australian Merino sheep in a summer-dominant rainfall environment:

Part I, Flock structure and phenotypes.

Part II, Phenotypic selection line differences and fixed effects.

Part III, Genetic parameters for breech strike and potential indirect selection criteria.

Part IV, Genetic associations between yearling fleece traits and potential indirect selection criteria for breech strike.

5.6 Implications

The phenotypic and genetic differences between selection lines observed in this flock were both statistically significant and commercially valuable and were achieved from several sources. There was an initial buy-in of ewes and assignment to selection lines based on phenotype. Particularly in the early years, there was across-flock selection of sires. The within-flock selection emphasis was strongly focussed on the disease trait and its indicators, rather than on production traits. All of these methods of achieving genetic change are available to sheep producers, albeit perhaps to varying degrees. For example, few Merino breeders are likely to change-over their breeding flock to a barer or plainer sheep type. This would be a very expensive exercise. However, the genetic gains demonstrated here suggest such a move would be unnecessary, given there is clearly genetic gain to be made by within-flock selection both on breech strike itself (simply through culling animals that become breech struck), and through indirect selection on traits such as breech wrinkle. Strategic selection of external sires could assist this process. The genetic gains achieved during the 10 year life of this study are probably greater than most breeders in industry could expect or achieve. This is primarily due to commercial reality which dictates greater selection emphasis on production traits than the disease trait, than was the case here.

Selective breeding for breech strike resistance has different methodology for different sectors of the Merino industry. Stud breeders who participate in across-flock genetic evaluation (Merino Select) can make use of across-flock ASBVs for indirect selection criteria which have been available since 2009, to aid selection decisions for replacement ewes, home-bred sires and external (link) sires. Stud breeders who do not participate in across-flock genetic evaluation, and commercial sheep producers, who together run the majority of Merino sheep in Australia, can conduct phenotypic selection on ewes and sires. For example, culling any animal that becomes breech struck; culling the most wrinkly, daggy, or highest breech cover animals in their flocks; and using across-flock performance information where appropriate in purchasing sires or semen. While phenotypic selection will be less accurate than using the more formal approach, a degree of genetic gain in breech strike resistance remains achievable.

6. EVALUATION OF TAIL-DOCKING METHODS IN RELATION TO LATER-AGE BREECH STRIKE

6.1 Methodology

6.1.1 Sheep

Progeny alive at marking from the Armidale breech strike genetics flock born in 2012 (n=466) and 2013 (n=439) were used in an investigation of the effect of tail docking method on later-age breech strike risk.

6.1.2 Experimental design

There were four treatments, being tail-docking method:

- Regular hot docking iron (HOT)
- Te Pari Patesco hot docking iron (TPP)
- Knife (COLD)
- Elastrator ring (RING).

The same lamb-marking contractor was engaged in both years and the brief was to dock female lambs to the tip of the vulva, and males to equivalent length or slightly shorter.

Prior to lamb marking (median age 36 days), lambs were assigned within selection lines (Resistant and Susceptible) to one of the four treatments. Groups were balanced for sire, sex, birth-rearing type, age of dam, and age.

6.1.3 Measurements

Breech strike was recorded throughout the following flystrike seasons as the count of breech strikes for the season. Details of the flystrike challenge period and procedure for phenotyping are reported in AWI Project WP639 TMS03, but usually run through the spring-summer-autumn. Overall, 2012-13 was a higher flystrike challenge year than 2013-14 and 2014-15.

For the 2012 drop:

1. Weaner, 2012-13 fly season (all progeny), mean wBRSTR = 18.5%
2. Yearling, 2013-14 fly season (all progeny), mean yBRSTR = 11.1%
3. Adult, 2014-15 fly season (only females retained in the breeding flock), mean a1BRSTR = 9.9%

For the 2013 drop;

1. Weaner, 2013-14 fly season (all progeny), mean wBRSTR = 12.8%
2. Yearling, 2014-15 fly season (all progeny), mean yBRSTR = 13.2%

Lambs were weighed (mWT) immediately prior to tail-docking, but that information was not available for the assignment of lambs to treatment groups. Mean bodyweights at marking, weaning and yearling were 11.1kg, 22.4kg and 38.1kg respectively.

Docked tail length (DTL) was measured using a ruler (to 5mm) at post-weaning (approx. 6 months of age). Mean DTL was 50mm (sd 12mm).

6.1.4 Statistical Analysis

Analysis of variance was conducted using a mixed animal model using ASReml (Gilmour *et al.* 2008). The traits examined were weaner, yearling and adult breech strike (wBRSTR, yBRSTR, and aBRSTR) square-root transformed. Tail docking method (4 levels, HOT, TPP, COLD, RING) was fitted as a fixed effect. Docked tail length was fitted as a covariate. Selection line (2 levels, Resistant and Susceptible); and birth-rearing type (3 levels, born and reared single/born multiple and reared single/born and reared multiple) were also fitted to all three breech strike traits. In addition, birth year (2 levels, 2012 and 2013); sex (2 levels, male and female) and age of dam (2 levels, maiden and adult) were fitted to wBRSTR and yBRSTR. Only 2012 drop females were present for the adult breech strike records and they were all from adult dams. Weaner and yearling age and bodyweight were fitted to wBRSTR and yBRSTR respectively. Fertility (2 levels, pregnant/not) and number of lambs weaned (NLW) were fitted as fixed effects to a1BRSTR. First order interactions among drop, line and sex were also tested as appropriate for significance for all three breech strike traits. Non-significant fixed effects and interactions were iteratively removed from the statistical model. Summary statistics for the 3 breech strike traits are reported in Table 26.

Table 26. Summary statistics for breech strike traits.

Trait	Mean	SD	Min	Max	Skewness	Kurtosis
wBRSTR	0.157	0.420	0	2	2.74	7.08
yBRSTR	0.121	0.386	0	3	3.58	14.42
a1BRSTR	0.251	0.543	0	3	2.32	5.51

6.2 Results and Discussion

6.2.1 Weaner breech strike

Birth year ($P<0.05$), selection line ($P<0.01$), sex ($P<0.05$), birth-rearing type ($P<0.05$) and weaning weight ($P<0.01$) were significant effects on wBRSTR. These effects were not unexpected and have been observed in previous years in this flock. Age of dam, weaning age, and docked tail length were non-significant effects on wBRSTR.

Tail docking method was a non-significant effect on wBRSTR, but there was a significant ($P<0.05$)birth year by tail docking method interaction whereby TPP resulted in significantly higher wBRSTR than the other tail docking methods among weaners born in 2013. Breech strike rates (back-transformed means) by birth-year and sheep class are detailed in Table 24.

6.2.2 Yearling breech strike

As for wBRSTR, birth year (P<0.01), selection line (P<0.001), sex (P<0.001) and yearling weight (P<0.001) were significant effects on yBRSTR. Tail docking method was a non-significant effect on yBRSTR, as was the interaction with birth year.

6.2.3 Adult breech strike

Only the 2012 drop ewes had adult breech strike records. Selection line was a significant effect on a1BRSTR. Tail docking method was a non-significant effect on a1BRSTR. There was a suggestion that RING resulted in lower breech strike rate in adult ewes: 11% compared to more than 20% for the other methods, but the smaller sample size (single drop of ewes only) resulted in higher s.e. than at the younger ages.

Fertility was a significant effect on a1BRSTR (P<0.01). Ewes that were pregnant to lamb at the start of the flystrike season exhibited lower a1BRSTR rate than dry ewes (19% versus 31%). The effect of NLW had a similar trend to fertility but was not statistically significant. a1BRSTR among ewes that reared 0, 1 or 2 lambs were 35%, 20% and 11% respectively.

Table 27 shows breech strike rates across the tail docking methods. In summary, there is no evidence for a consistent effect of tail docking method on breech strike rates. Based on results from this study, no firm conclusion can be drawn about the relative merits of different tail docking methods with respect to later-age breech strike rates. There may be implications of the different tail docking methods with respect to post-tailing infection rates, lamb welfare at tail docking etc., but they were not the subject of this study.

Table 27. Summary of breech strike rates among weaners, yearlings and adult ewes born in 2012 and 2013 (back-transformed mean (%)). Within years and sheep classes, arrows indicate non-significant differences between treatments.

2012 drop				
weaners	**TPP**	**HOT**	**RING**	**COLD**
	13.5	15.6	15.8	21.2
	←	—	→	
		←	—	→
yearlings	**TPP**	**COLD**	**HOT**	**RING**
	5.1	5.3	6.3	6.4
	←	—	—	→

adults	**RING**	**HOT**	**TPP**	**COLD**
	11.3	21.9	24.0	24.2
2013 drop				
weaners	**COLD**	**HOT**	**RING**	**TEPARI**
	5.3	8.0	8.2	16.1
yearlings	**HOT**	**TPP**	**COLD**	**RING**
	12.3	13.6	14.5	16

6.2.4 Docked tail length

Docked tail length, recorded at post-weaning (approx. 6mo) was normally distributed with mean = 56mm, sd = 15mm, and range 20-105mm. Few animals had docked tails of less than 30mm (n=5), or docked tails of greater than 90mm (n=11).

As mentioned above, docked tail length was a non-significant effect on breech strike rates among weaners, yearlings and ewes. This result is inconsistent with the literature (reviewed by Lloyd 2012) which indicates animals with tails docked short tend to be more likely to become breech struck than those with tails docked longer. Figure 13. shows arithmetic mean breech strike rates among the three classes of sheep by docked tail length category. In this flock, the relationship between docked tail length and breech strike is non-linear. The few animals with either very short or very long docked tails experienced higher rates of breech strike than those with intermediate docked tails.

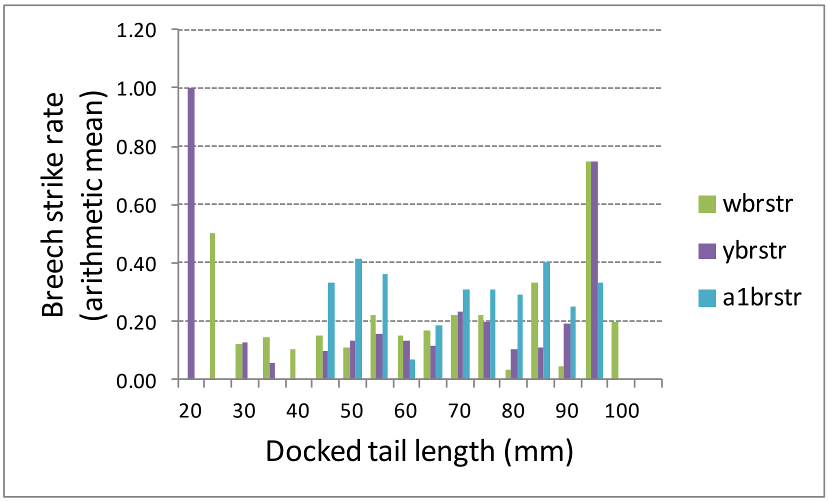

Figure 13. Breech strike rate across the range of docked tail lengths

In addition to the analyses of breech strike rates arising from the different tail docking methods, docked tail length was also examined with respect to the tail docking methods. The brief to the tail-docking contractor was common across years and tail docking methods.

An analysis of variance was conducted to test the effect of tail docking method, year and sex on docked tail length. Docked tail length was longer in 2012 than 2013 (59.54 (0.44) versus 51.28 (0.45), P<0.001), and docked tail length of females was longer than males (65.88 (0.41) versus 45.21 90.41), P<0.001). Despite a common brief to the contractor for all methods, they resulted in different docked tail lengths with all 4 methods being significantly different from each other (HOT 62.34 (0.59), TPP 56.47 (0.59), COLD 53.29 (0.58), RING 50.39 (0.57), P<0.001). There was also a significant year x method interaction with change in rank of TPP and COLD. However, in both years HOT resulted in the longest docked tails and RING resulted in the shortest docked tails.

Evidence from other studies indicates docked tail length affects susceptibility to breech strike. Animals with the tails docked short have been shown to be more likely to become breech struck than those with tails docked longer. In the current study there was indication that animals with either very short or very long docked tails were more likely to become breech struck than those with intermediate tails, but there were few animals, and therefore high error associated with the records at the extremes.

Despite a common brief to the contractor with respect to docked tail length, the different tail docking methods resulted in different docked tail lengths. This effect was consistent across years. This may be important information for those persons conducting tail docking (either contractors or owners/employees) to be aware of the likely end result for different tail docking methods. For example, if docking using rings, it may be prudent to err on the side of caution and place the ring a little lower than if using a knife, in order to achieve the same effect.

6.3 Implications

There is no evidence from this study for a consistent effect of tail-docking method on later age breech strike. Hence, from the perspective of breech strike risk there is no clear ‘preferred method’ among those tested. There may be certain methods that are preferred from an animal welfare perspective, but that is the subject of other studies and is not for comment here.

7. IMPACT ON WOOL INDUSTRY – NOW & IN FIVE YEARS' TIME

- This work has contributed to development of the guidelines to industry around which traits to concentrate on, when and how to record them. This information is available to industry through Sheep Genetics, the Sheep Visual Scores book, and the ParaBoss website.
- Genetic parameters estimated in the course of this work have contributed to the Sheep Genetics development and release of ASBV's for breech wrinkle, breech cover and dag. Approximately 30% of current drop progeny recorded in MerinoSelect have ASBV for at least one of the breech strike indicator traits.
- Phenotype data collected in the course of this work has contributed to development of the tools available on ParaBoss for flystrike risk and management optimisation, and comparison of management systems.
- AWEX statistics on the National wool Declaration indicate the proportion of the National wool clip declared as unmulesed is increasing at 2-3% pa.
- Animal welfare organisations have been kept informed of progress in this research area through participation in the AWI Welfare Forum.

8. CONCLUSIONS AND RECOMMENDATIONS

The work conducted in this Project and its two predecessors (AWI Projects WP468 and EC940) has made significant contribution toward enabling industry to incorporate breech strike selection into Merino breeding programs. The work conducted and the results obtained at Armidale relate particularly to fine wool sheep in a summer dominant rainfall environment and it has been shown that breech wrinkle is a key indicator trait. A different set of traits may be more appropriate in other environments, as shown by the DAFWA medium wool flock at Mt Barker, WA (Mediterranean environment).

Hence, methods and tools to be applied by individuals to breed for breech strike should be dependent upon the type of sheep and wool they are working with, the production system, and the environment in which they operate. Unfortunately, there is no 'one-size-fits-all' solution to breeding for breech strike resistance.

While much of the knowledge gained and methods developed during the life of these Projects on breech strike genetics have their main application in the stud industry, certain aspects have equal application for commercial sheep producers.

These Projects have not 'solved' the problem of breech strike in Merinos, but they have made significant inroads into developing the methods to enable genetic improvement in breech strike resistance. Results from the Armidale site demonstrate that genetic improvement through the use of indirect selection criteria can be a commercial reality. There may be further discoveries in the future to come from the WA teams work on odour, or from the CSIRO's genomics study, that will enhance our ability to breed breech strike resistant sheep and reduce reliance on the practice of mulesing.

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11. LIST OF ABBREVIATIONS

aBRSTR	adult breech strike
ASBV	Australian sheep breeding value
AWEX	Australian Wool Exchange
AWI	Australian Wool Innovation Ltd
b	birth
BCOV	Breech cover
BD	Breech bare depth
BRWR	Breech wrinkle
BW	Breech bare width
BWR	body wrinkle
CFW	clean fleece weight
COL	greasy wool colour
COLD	cold knife (for tail docking)
CRIMP	crimp definition
CSIRO	Commonwealth Scientific and industrial Research Organisation
CURV	mean fibre curvature
CVD	Coefficient of variation of fibre diameter
DAG	dags
DNA	Deoxyribonucleic acid, genetic material
DTL	docked tail length
eBCOV	early breech cover
eBRWR	early breech wrinkle
FD	fibre diameter
FLROT	fleece rot
GFW	greasy fleece weight
HOT	regular hot docking iron
lDAG	late dag
m	marking
MM	Born and reared multiple
MS	Born multiple, reared single
MSS	Merino Superior Sires

mWT	marking-age body weight
NLW	number of lambs weaned
NSW DPI	New South Wales Department of Primary Industries
NWR	Neck wrinkle
P	probability
p	post-weaning
R&D	research and development
RING	elastrator ring (for tail docking)
S	Born and reared single
SCRC	Sheep Cooperative Research Centre
sd	standard deviation
SDFD	standard deviation of fibre diameter
se	standard error
SL	staple length
SNP	single nucleotide polymorphism
SS	staple strength
TL	tail length
TPP	te Pari Patesco docking iron
URINE	urine stain
UWA	University of Western Australia
w	weaning
WA	Western Australia
wBRSTR	weaner breech strike
WT	body weight
y	yearling
yBRSTR	yearling breech strike
YLD	washing yield