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How does ewe age affect reproductive performance relative to rainfall conditions?

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Abstract

With climate change and its associated impacts on weather patterns being an inescapable reality, livestock producers will have to explore management and mitigation strategies to maintain production levels under adverse weather conditions. It is well-documented that ewe age affects reproductive performance, but it is unclear whether this phenomenon can be utilised to mitigate the effects of adverse environments. This study aimed to determine whether certain ewe age groups are better adapted to reproduce under specific rainfall conditions. Historical rainfall data collected on Tygerhoek Research Farm, South Africa, between 1975 and 2018 was used to group production seasons into five rainfall classes: dry, below average, average, above average, and wet. Ewe performance traits (conception rate, number of lambs born, number of lambs weaned, average birthweight, and average weaning weight) were calculated for each age group (2–6 years) across all seasons and within each rainfall class. Age group performance for each trait in each rainfall class was compared to the overall trend to see if any marked differences existed. Overall, reproduction rate was maximal at three to four years of age, and this trend was largely repeated for each rainfall class. Birthweight increased with age except in wet seasons, when no discernible trend was present, while weaning weight was highest in three- and four-year-old ewes. In dry seasons, however, there was a clear trend for weaning weight to increase as ewes aged. It was concluded that flock age structure cannot be used to mitigate environmental impacts if a flock is already structured to optimise reproduction.

Keywords: age effects, climate change, environmental effects, Merino, reproduction

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Introduction

Sheep farming, both for commercial and subsistence purposes, has traditionally played an important role in the South African agricultural landscape, with nomadic groups keeping flocks of indigenous breeds as early as 200 AD (Snyman, 2014), and European settlers most notably introducing the Merino breed to the country in the 1700s (Bath, 2023). Several highly successful commercial composite breeds were also developed during the 1900s (SA Stud Book, 1998; Milne, 2000). Because

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of their natural adaptability and hardiness, the majority of the more than 18 million sheep (DALRRD, 2022) in the country can be found in the arid western region, and are primarily kept under extensive conditions (Cloete & Olivier, 2010). The aridity of this region makes extensive livestock farming the only viable agricultural enterprise that can be practiced in the area (FAOSTAT, 2020). However, the adaptability of sheep to various environments and production systems (Akinmoladun *et al.*, 2019) has resulted in large numbers also being kept in ley farming or mixed crop-livestock systems in some cropping areas of the country (Cloete & Olivier, 2010). These higher producing regions, primarily in the Western Cape, are responsible for a significant proportion of sheep and lamb production (Red Meat Industry Services, 2024).

All extensive production systems, regardless of where they are located, are heavily reliant upon favourable weather conditions, particularly adequate rainfall, to remain viable (Li *et al.*, 2012; Rust & Rust, 2013; Oduniyi *et al.*, 2020), and are therefore vulnerable to any fluctuations in weather patterns. Global climate change has the potential to significantly affect weather patterns, and Southern Africa is considered particularly susceptible (Jury, 2013; Meissner *et al.*, 2013; Akinnagbe & Irohibe, 2014; Gizaw & Gan, 2017; Lottering *et al.*, 2021). Some changes in weather patterns can already be observed in the region, with Ziervogel *et al.* (2014) and Pereira (2017) reporting that temperatures were increasing at a greater rate than the global average, and predictions suggest that this trend will continue (Jury, 2013; Meissner *et al.*, 2013; Niang *et al.*, 2014; Scholtz *et al.*, 2016; Gizaw & Gan, 2017). Over the last century, the mean annual rainfall in South Africa has slowly declined (Jury, 2013; Niang *et al.*, 2014) and this trend is predicted to continue and potentially even accelerate in the future (Jury, 2013; Meissner *et al.*, 2013; Niang *et al.*, 2014; Pereira, 2017). This naturally increases the possibility of droughts occurring in the region (Pereira, 2017; Ruwanza *et al.*, 2022).

Droughts have been described as the most challenging, complex (Lottering *et al.*, 2021), and costly (Mare *et al.*, 2018) forms of natural disaster the world experiences, with two-thirds of sub-Saharan Africa considered particularly susceptible (Muyambo *et al.*, 2017). This, coupled with the various climate projections mentioned above, indicates that the conditions under which livestock producers will have to operate are likely to become increasingly unfavourable. With weather and climate having the potential to negatively impact the production, health, and welfare of farm animals (Nardone *et al.*, 2006), this is a major cause for concern for producers.

In order for their enterprises to remain viable, producers will have to explore various avenues of production optimisation and methods of adapting to unfavourable environmental conditions. This can generally be achieved through breeding programmes, if sufficient genetic variation is present (Cloete *et al.*, 2023), but management strategies and flock structure will also play an important part.

The effect of ewe age on reproductive performance has been well-documented (Aktaş *et al.*, 2015; Shorten *et al.*, 2021; Pettigrew *et al.*, 2021; Hutchison *et al.*, 2022; Nel *et al.*, 2022; Myrtill *et al.*, 2023) and there is universal agreement that it has a significant impact on reproduction. Maiden or primiparous ewes (ewes lambing for the first time) generally display lower conception rates (Nel *et al.*, 2022), lambing percentages (Cloete *et al.*, 2021; Hutchison *et al.*, 2022), birthweights (Aktaş *et al.*, 2015; Pettigrew *et al.*, 2021), lamb survival rates (Shorten *et al.*, 2021; Hutchison *et al.*, 2022), and weaning weights (Aktaş *et al.*, 2015; Pettigrew *et al.*, 2021) than mature ewes. However, there are also differences in reproductive performance between mature ewes of different ages, with some traits showing a decline in performance beyond a certain age (Aktaş *et al.*, 2015; Cloete *et al.*, 2021; Shorten *et al.*, 2021). It is therefore clear that there is an optimal age structure for a flock, where sufficient young ewes are available as replacement animals but the majority of the flock consists of mature animals of optimal reproductive age.

Such a mixed-age flock kept on a farm would be exposed to the same environmental conditions, but the different age groups may respond differently to these conditions. If certain age groups perform better under unfavourable conditions, it would be advantageous for producers to be able to identify these groups and potentially change the age structure of their flocks to improve reproductive performance in poor years.

This study was therefore carried out to determine whether the effect of dam age on reproductive performance varied depending on the environmental conditions the flock was exposed to prior to mating. The hypothesis proposed for this study was that rainfall effects could modulate age effects to a certain degree.

Methodology

This study was conducted using historical production and weather data collected on Tygerhoek Research Farm (34°10’ S, 19°54’ E) in the Western Cape of South Africa. The region has a Mediterranean climate with an average maximum temperature of 23.6 °C and receives the majority of its 480 mm of annual rainfall in winter (June to August). According to the amount of rainfall received, it can be classified as a semi-arid area (Maliva & Missimer, 2012).

The production data used in the study consisted of individual records from the Tygerhoek Merino flock collected as part of the standard recordkeeping procedure on the farm. As such, no ethical clearance was required for this project. The flock is maintained on dryland pastures, chiefly lucerne and medics. Oat fodder is also available during winter and spring, and wheat stubble, supplemented with oat grains, during summer. Ewes are hand mated to selected rams from October to December each year and the lambing season is therefore from March to May (autumn). The reason for the extended mating season is that some ewes do not conceive at the first mating opportunity and therefore undergo subsequent matings. Lambs were weaned at approximately 100 days of age throughout the data collection period. For this study, a production season was defined as the period between the current mating and the beginning of the next mating season, and extended from October in year *y* to September in year *y+1*.

The production records used in this study were collected between 1976 and 2018 and included ewe measurements for the following traits: conception, number of lambs born (NLB), number of lambs weaned (NLW), average birthweight (ABW), and average weaning weight (AWW). Conception is a binary trait and is defined as whether mating resulted in the ewe carrying a foetus to term or not. The number of lambs born and weaned were calculated per ewe mated. Birth and weaning weights were calculated as the average weight born or weaned per ewe lambed. Because insufficient records were available for animals older than six years, only records for ewes between two and six years of age were retained. After removing duplicate and incomplete records from the dataset, 16 382 individual entries across 41 production seasons were included in the final dataset.

Weather data were sourced from a weather station maintained on the farm by the Agricultural Research Council. For this study, only rainfall records were needed and daily rainfall measurements were used to calculate total rainfall per production season. No data were available for 1995 and 2005 and therefore the 1995/1996 and 2005/2006 production seasons were excluded from the dataset. As the study’s aim was to consider the effect of rainfall in the preceding production season on production in the current season, the rainfall record for season *n−1* was linked to the production record for season *n*.

Production seasons were divided into five classes based on the total rainfall in the 12 months preceding mating, with the following classes being defined: dry, below average, average, above average, and wet. Average seasons were defined as seasons where rainfall was within 10% (either above or below) of the long-term mean seasonal rainfall. Above- and below-average seasons had rainfall between 10% and 30% above or below the average, respectively, and wet and dry seasons deviated more than 30% from the average. The exact cut-off points for each category are given in Table 1.

Table 1 Criteria according to which seasons were allocated to rainfall classes

Classification	Lower limit (mm/season)	Upper limit (mm/season)	Percentage of average rainfall
Dry	NA	336.33	<70% of mean seasonal rainfall
Below average	336.34	432.43	70%–90% of mean seasonal rainfall
Average	432.44	528.53	90%–110% of mean seasonal rainfall
Above average	528.54	624.62	110%–130% of mean seasonal rainfall
Wet	624.63	NA	>130% of mean seasonal rainfall

Statistical analysis was conducted using Statistica 14 (TIBCO Statistica, 2020). The data were found to have unequal variances, and non-parametric tests were therefore employed. A Welch analysis of variance test was performed on the full dataset to determine the effect of age on the various production traits, regardless of the influence of rainfall. Where significant differences at a level of $P \leq 0.05$ were present, Games-Howell multiple comparisons were used to quantify the differences between the means.

The same procedure was then followed within each rainfall class to determine whether the trends seen in the first analysis were affected by rainfall. Since the number of years and therefore individual records differed widely between seasons, it was decided to not directly compare the level of production between the rainfall classes.

Results

Table 2 and Table 3 summarise the structure of the complete dataset. As expected, the majority of the seasons (34%) were classified as average with regards to rainfall. Although only four and five seasons were classified as dry and wet, respectively, there were still enough individual records present to capture sufficient variation between age groups in these seasons to justify the analysis and validate any conclusions drawn from it.

Table 2 Summary of the rainfall classification composition of the dataset used in the analysis

Classification	Number of seasons	%	Number of records	%
Dry	4	10	1696	10
Below average	10	24	4144	25
Average	14	34	5436	33
Above average	8	20	3277	20
Wet	5	12	1829	11

Table 3 Descriptive statistics for the reproductive traits recorded for the Tygerhoek Merino flock between 1976 and 2018

Variable	n	Mean	Minimum	Maximum	SD	CV
Conception	16 382	0.7	0.0	4.0	0.5	66.6
Number of lambs born	16 382	1.0	0.0	5.0	0.8	80.4
Number of lambs weaned	16 368	0.7	0.0	4.0	0.7	101.5
Average birth weight (kg)	11 129	3.8	0.5	9.7	0.9	25.1
Average weaning weight (kg)	7952	26.1	10.0	61.0	7.2	27.8

SD: standard deviation, CV: coefficient of variation.

The effect of age on reproductive performance across all years is indicated in Table 4. Age significantly affected all the traits included in the study. The conception, NLB, and NLW values indicate the number of lambings, lambs born, and lambs weaned per ewe mated, respectively.

Overall, maiden (or primiparous) ewes displayed the lowest values for conception, NLB, and NLW, although their conception values did not differ from those of five- and six-year-old ewes. Conception was highest in three-year-old ewes, while three- and four-year-old ewes had higher values for NLB and NLW than the other age groups but did not differ from each other. Five- and six-year-old ewes had intermediate values for both of these traits.

Average birthweight increased with ewe age. Four- to six-year-old ewes delivered lambs of similar weights that were heavier than lambs from younger ewes. Maiden ewes again had significantly lower values than all the other age groups. Weaning weight was highest in three- to five-year-old ewes, with their lambs being significantly heavier at weaning than those of two- and six-year-olds.

Table 4 The effect of ewe age on the reproductive performance (mean ± standard error) of the Tygerhoek Merino flock

Ewe age	n	Conception	NLB	NLW	ABW (kg)	AWW (kg)
2 years	3596	$0.68^{c} \pm 0.01$	$0.86^{c} \pm 0.01$	$0.60^{c} \pm 0.01$	$3.62^{c} \pm 0.02$	$25.37^{b} \pm 0.18$
3 years	3388	$0.75^{a} \pm 0.01$	$1.03^{a} \pm 0.01$	$0.75^{a} \pm 0.01$	$3.76^{b} \pm 0.02$	$26.73^{a} \pm 0.17$
4 years	3292	$0.72^{b} \pm 0.01$	$1.04^{a} \pm 0.01$	$0.77^{a} \pm 0.01$	$3.83^{a} \pm 0.02$	$26.37^{a} \pm 0.17$
5 years	3062	$0.66^{c} \pm 0.01$	$0.96^{b} \pm 0.01$	$0.69^{b} \pm 0.01$	$3.85^{a} \pm 0.02$	$26.40^{a} \pm 0.19$
6 years	3044	$0.65^{c} \pm 0.01$	$0.97^{b} \pm 0.02$	$0.68^{b} \pm 0.01$	$3.84^{a} \pm 0.02$	$25.48^{b} \pm 0.20$
***P*-value**		<0.001	<0.001	<0.001	<0.001	<0.001

NLB: number of lambs born, NLW: number of lambs weaned, ABW: average birthweight, AWW: average weaning weight. ^{abc} Means with different superscripts in the same column differ significantly at $P \leq 0.05$.

Tables 5–9 summarise the relative performances of each age group within the five rainfall classes. Ewe age was found to significantly affect all traits studied, regardless of rainfall class, with the exception of the ABW in seasons with above-average rainfall ($P = 0.078$), where it only tended towards significance.

In dry seasons (Table 5), when less than 70% of the average rainfall was received, six-year-old ewes had the lowest conception rates, although this was not significantly lower than that of five-year-olds, which, in turn, did not differ from that of maiden ewes. Three- and four-year-olds had the highest conception rates, although these were not significantly greater than that of two-year-olds. Four-year-old ewes gave birth to significantly more lambs than two- and five-year-olds, while three- and six-year-olds birthed intermediate numbers of lambs and did not differ from either of the other groups. The NLW per ewe mated was again highest in four-year-olds, being significantly higher in this age group than all other age groups, except three-year-olds. Maiden ewes weaned the lowest number of lambs per ewe, performing similarly to five- and six-year-olds, with the latter two ages also not differing from three-year-olds. For the ABW, maiden ewes had the lowest values, and these were significantly lower than the ABWs of all the other age groups, which did not differ from one another. Weaning weight was significantly higher in five- and six-year-olds than in maiden ewes and three-year-olds, while four-year-olds did not differ from any other group.

Table 5 The effect of ewe age on the reproductive performance (mean ± standard error) of the Tygerhoek Merino flock during dry seasons (seasons receiving less than 70% of average rainfall)

	Age	n	Conception	NLB	NLW	ABW (kg)	AWW (kg)
Dry	**2**	321	$0.68^{ab} \pm 0.03$	$0.81^{b} \pm 0.04$	$0.60^{c} \pm 0.04$	$3.55^{b} \pm 0.06$	$25.96^{b} \pm 0.52$
	3	315	$0.71^{a} \pm 0.03$	$0.96^{ab} \pm 0.04$	$0.77^{ab} \pm 0.04$	$3.80^{a} \pm 0.06$	$27.15^{b} \pm 0.57$
	4	366	$0.71^{a} \pm 0.02$	$1.02^{a} \pm 0.04$	$0.80^{a} \pm 0.04$	$3.76^{a} \pm 0.06$	$28.01^{ab} \pm 0.58$
	5	323	$0.59^{bc} \pm 0.03$	$0.84^{b} \pm 0.04$	$0.64^{bc} \pm 0.04$	$3.90^{a} \pm 0.06$	$29.96^{a} \pm 0.80$
	6	371	$0.57^{c} \pm 0.03$	$0.87^{ab} \pm 0.05$	$0.64^{bc} \pm 0.04$	$3.86^{a} \pm 0.08$	$29.80^{a} \pm 0.73$
	***P*-value**		<0.001	0.002	<0.001	0.002	<0.001

NLB: number of lambs born, NLW: number of lambs weaned, ABW: average birthweight, AWW: average weaning weight. ^{abc} Means with different superscripts in the same column differ significantly at $P \leq 0.05$.

In seasons receiving below-average rainfall (70%–90% of the average), conception was highest in three-year-old ewes and lowest in two- and four-year-olds (Table 6). Five- and six-year-olds did not differ from the other age groups. Primiparous ewes had significantly lower NLB values than the other age groups, all of which performed similarly, birthing more than one lamb per ewe mated. Two-year-olds also weaned significantly fewer lambs than any other age group. The highest NLW value was observed in three-year-olds, even though it was not significantly higher in this group than in four- and five-year-olds. Six-year-olds also performed similarly to the latter two age groups. Average birthweight was once again significantly lower in maiden ewes than in the other age groups, while four- to six-year-olds displayed similar ABW values, which were higher than those of the three-year-olds. In below-average years, maiden ewes also had the lowest AWW, although this did not differ significantly from that of four-year-olds. In turn, four-year-old ewes did not differ from five- and six-year-olds, with these also being similar to three-year-olds, which had the highest AWW.

Table 6 The effect of ewe age on the reproductive performance (mean ± standard error) of the Tygerhoek Merino flock during below-average seasons (seasons receiving 70%–90% of average rainfall)

	Age	n	Conception	NLB	NLW	ABW (kg)	AWW (kg)
Below-average rainfall	**2**	903	$0.70^{b} \pm 0.01$	$0.88^{b} \pm 0.02$	$0.59^{c} \pm 0.02$	$3.50^{c} \pm 0.03$	$23.20^{c} \pm 0.28$
	3	885	$0.78^{a} \pm 0.01$	$1.08^{a} \pm 0.02$	$0.78^{a} \pm 0.02$	$3.63^{b} \pm 0.03$	$24.76^{a} \pm 0.25$
	4	860	$0.72^{b} \pm 0.02$	$1.03^{a} \pm 0.03$	$0.74^{ab} \pm 0.02$	$3.83^{a} \pm 0.04$	$23.77^{bc} \pm 0.27$
	5	801	$0.75^{ab} \pm 0.02$	$1.07^{a} \pm 0.03$	$0.74^{ab} \pm 0.02$	$3.84^{a} \pm 0.04$	$24.05^{ab} \pm 0.30$
	6	695	$0.73^{ab} \pm 0.02$	$1.08^{a} \pm 0.03$	$0.68^{b} \pm 0.03$	$3.90^{a} \pm 0.05$	$24.44^{ab} \pm 0.33$
	***P*-value**		0.003	<0.001	<0.001	<0.001	<0.001

NLB: number of lambs born, NLW: number of lambs weaned, ABW: average birthweight, AWW: average weaning weight. [abc] Means with different superscripts in the same column differ significantly at $P \leq 0.05$.

In average rainfall seasons (Table 7), when rainfall was between 90% and 110% of the long-term average, it was expected that the trends would be very similar to the overall trends in Table 4. Because more seasons (33%) were classified as having received average rainfall than any other group, it was reasonable to suppose that this group would have the largest influence on overall performance. Furthermore, since long-term performance averages out the extremes and the average rainfall class excludes rainfall extremes, it was supposed that there might be considerable overlap between the results.

Table 7 The effect of ewe age on the reproductive performance (mean ± standard error) of the Tygerhoek Merino flock during average seasons (seasons receiving 90%–110% of average rainfall)

	Age	n	Conception	NLB	NLW	ABW (kg)	AWW (kg)
Average rainfall	**2**	1226	$0.62^{c} \pm 0.01$	$0.75^{c} \pm 0.02$	$0.55^{c} \pm 0.02$	$3.55^{c} \pm 0.03$	$25.82^{ab} \pm 0.31$
	3	1137	$0.72^{a} \pm 0.01$	$0.95^{a} \pm 0.02$	$0.71^{ab} \pm 0.02$	$3.66^{b} \pm 0.03$	$26.13^{a} \pm 0.30$
	4	987	$0.69^{ab} \pm 0.02$	$0.95^{ab} \pm 0.02$	$0.74^{a} \pm 0.02$	$3.73^{ab} \pm 0.03$	$24.88^{b} \pm 0.27$
	5	1029	$0.60^{c} \pm 0.02$	$0.86^{b} \pm 0.03$	$0.65^{b} \pm 0.02$	$3.75^{a} \pm 0.03$	$25.27^{ab} \pm 0.33$
	6	1057	$0.66^{bc} \pm 0.01$	$0.94^{ab} \pm 0.02$	$0.70^{ab} \pm 0.02$	$3.75^{a} \pm 0.03$	$24.83^{b} \pm 0.28$
	***P*-value**		<0.001	<0.001	<0.001	<0.001	0.004

NLB: number of lambs born, NLW: number of lambs weaned, ABW: average birthweight, AWW: average weaning weight. [abc] Means with different superscripts in the same column differ significantly at $P \leq 0.05$.

This was not quite the case, although some similarities were present. Conception was lowest in maiden ewes and five-year-olds, with six-year-olds having similar conception rates to these two groups. Six-year-old ewes also had similar conception rates to four-year-olds, which, in turn, did not differ from three-year-old ewes, for which the highest conception rate was found. The NLB was highest in the three-year-olds, but this did not significantly differ from the four- and six-year-olds. The latter two age groups also did not differ from five-year-old ewes in terms of their NLB. As before, maiden ewes had significantly lower NLB values than any other age group. This also held true for the NLW, for which all other groups displayed significantly higher values, with four-year-olds performing best. They did not, however, differ significantly from the three- or six-year-olds, which also performed similarly to five-year-olds. The highest ABW values were observed in five- and six-year-old ewes during average years. However, these groups did not differ significantly from four-year-old ewes, which, in turn, displayed similar birthweights to three-year-olds. Maiden ewes once again had the lowest ABW values. The AWW was highest in three-year-olds and lowest in four- and six-year-old ewes. Two- and five-year-olds did not differ from these groups.

No differences in conception rate were present between two-, three-, and four-year-olds in above-average rainfall seasons (seasons receiving 110%–130% of the average), with ewes in these age groups performing significantly better than five- and six-year-old ewes (Table 8). Four-year-olds had the highest NLB values, although this was not significantly higher than the NLB values for maiden and three-year-old ewes. In turn, five-year-olds did not differ from two- and three-year-olds or from six-year-olds, which had the lowest NLB. Four-year-old ewes also weaned significantly more lambs per ewe than any other age group, except the three-year-olds. Three-year-olds did not differ from the maiden or six-year-old ewes and the latter two groups did not differ from the five-year-olds, which had the lowest NLW. No statistically significant differences were present for the ABW. Maiden and six-year-old ewes had significantly lower AWW values than five-year-olds, which, in turn, differed significantly from three- and four-year-old ewes.

Table 8 The effect of ewe age on the reproductive performance (mean ± standard error) of the Tygerhoek Merino flock during above-average seasons (seasons receiving 110%–130% of average rainfall)

	Age	n	Conception	NLB	NLW	ABW (kg)	AWW (kg)
Above-average rainfall	**2**	715	$0.73^{a} \pm 0.02$	$0.93^{ab} \pm 0.03$	$0.63^{abc} \pm 0.03$	3.69 ± 0.04	$23.01^{c} \pm 0.35$
	3	653	$0.73^{a} \pm 0.02$	$0.94^{ab} \pm 0.03$	$0.70^{ab} \pm 0.03$	3.74 ± 0.04	$25.56^{a} \pm 0.35$
	4	657	$0.68^{a} \pm 0.02$	$0.97^{a} \pm 0.03$	$0.72^{a} \pm 0.03$	3.82 ± 0.05	$26.11^{a} \pm 0.35$
	5	588	$0.59^{b} \pm 0.02$	$0.83^{bc} \pm 0.03$	$0.57^{c} \pm 0.03$	3.81 ± 0.06	$24.34^{b} \pm 0.42$
	6	664	$0.54^{b} \pm 0.02$	$0.80^{c} \pm 0.03$	$0.59^{bc} \pm 0.03$	3.86 ± 0.05	$22.95^{c} \pm 0.40$
	***P*-value**		<0.001	<0.001	<0.001	0.078	<0.001

NLB: number of lambs born, NLW: number of lambs weaned, ABW: average birthweight, AWW: average weaning weight. [abc] Means with different superscripts in the same column differ significantly at $P \leq 0.05$.

Table 9 The effect of ewe age on the reproductive performance (mean ± standard error) of the Tygerhoek Merino flock during wet seasons (seasons receiving more than 130% of average rainfall)

	Age	n	Conception	NLB	NLW	ABW (kg)	AWW (kg)
Wet	**2**	431	$0.72^{b} \pm 0.02$	$1.01^{b} \pm 0.04$	$0.68^{c} \pm 0.04$	$4.00^{b} \pm 0.06$	$31.09^{b} \pm 0.46$
	3	398	$0.86^{a} \pm 0.02$	$1.35^{a} \pm 0.04$	$0.89^{ab} \pm 0.04$	$4.22^{a} \pm 0.05$	$33.05^{a} \pm 0.44$
	4	422	$0.84^{a} \pm 0.02$	$1.39^{a} \pm 0.04$	$0.97^{a} \pm 0.04$	$4.08^{ab} \pm 0.05$	$31.98^{ab} \pm 0.42$
	5	321	$0.84^{a} \pm 0.02$	$1.37^{a} \pm 0.05$	$0.95^{a} \pm 0.04$	$4.12^{ab} \pm 0.06$	$32.33^{ab} \pm 0.48$
	6	257	$0.81^{ab} \pm 0.02$	$1.32^{a} \pm 0.05$	$0.81^{b} \pm 0.05$	$3.97^{b} \pm 0.07$	$29.56^{c} \pm 0.58$
	***P*-value**		<0.001	<0.001	<0.001	0.028	<0.001

NLB: number of lambs born, NLW: number of lambs weaned, ABW: average birthweight, AWW: average weaning weight. [abc] Means with different superscripts in the same column differ significantly at $P \leq 0.05$.

Finally, performance in wet seasons (seasons receiving more than 130% of the average) was compared between the age groups (Table 9). Conception was highest in three- to five-year-olds, with this being significantly higher than in maiden ewes. Six-year-olds did not differ from either group. Maiden ewes had significantly lower NLB values than the other age groups, among which no differences were present. Despite two-year-old ewes once again performing significantly poorer than the other age groups, the NLW showed greater variation. Four- and five-year-olds had significantly higher NLW values than six-year-olds, with three-year-olds not differing from any group other than the maiden ewes. Average birthweight was highest in three-year-old ewes, with this being significantly higher than in two- and six-year-olds. Four- and five-year-olds had intermediate ABW values. Regarding the AWW, three-year-olds again had the highest values, while four- and five-year-olds had values between those of this group and the maiden ewes. Six-year-olds had significantly lower AWW than any other age group.

The results presented in Tables 4–9 are presented graphically in Figures 1–5 to simplify the representation of the trends seen in each trait relative to age. Figure a in each pair represents the effect of age on the selected trait across all rainfall classes, while Figure b indicates the trends in that trait in each rainfall class. Figure 1a therefore illustrates the effect of age on conception, regardless of rainfall, while Figure 1b demonstrates that same effect in each of the rainfall classes. Because of the differences between the number of seasons in each rainfall class, no attempt was made to statistically compare the ewes' performance between them.

When the rainfall effects are considered, the trend seen in Figure 1a changes. Conception rates in dry and wet seasons most closely followed the overall trend, but there was no marked decline between three and four years of age in either case, while five- and six-year-olds had better conception rates than maiden ewes in wet seasons (Figure 1b). In above-average seasons, there was a consistent decline in the conception rate as the ewes increased in age, although the differences between two-, three-, and four-year-old ewes was not significant. In average seasons, the same trend as the overall trend was seen until five years of age, whereafter there was a marked increase in the conception rate. Below-average seasons also showed peak conception at three years of age, but no differences between four-, five-, and six-year-olds were found.

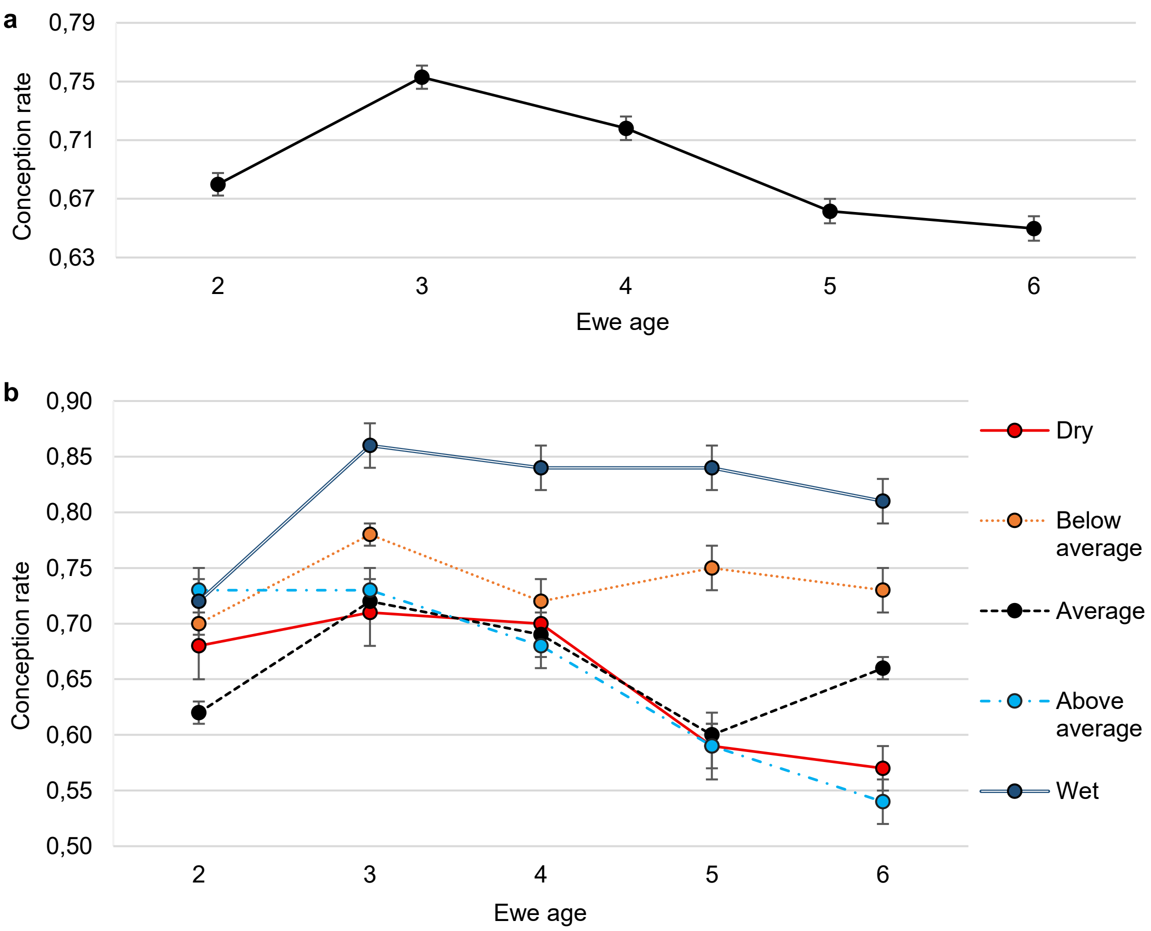


Figure 1 The effect of ewe age (in years) on conception rates (mean ± standard error) in the Tygerhoek Merino flock, on average (**a**) and across the different rainfall classes (**b**).

Overall, the NLB increased between two and three years of age, stayed constant between three and four years, declined between four and five years, and then remained constant until six years of age (Figure 2a). In wet seasons (Figure 2b), the overall trend for the NLB was followed quite closely. In average and dry seasons, the trend was followed until five years of age, but there was a non-significant increase in the NLB in six-year-old ewes that was not seen in the overall trend. During below-average rainfall seasons, the NLB increased after the age of two years, but stayed fairly constant thereafter. The NLB in above-average rainfall seasons remained constant until four years of age, followed by a decline thereafter.

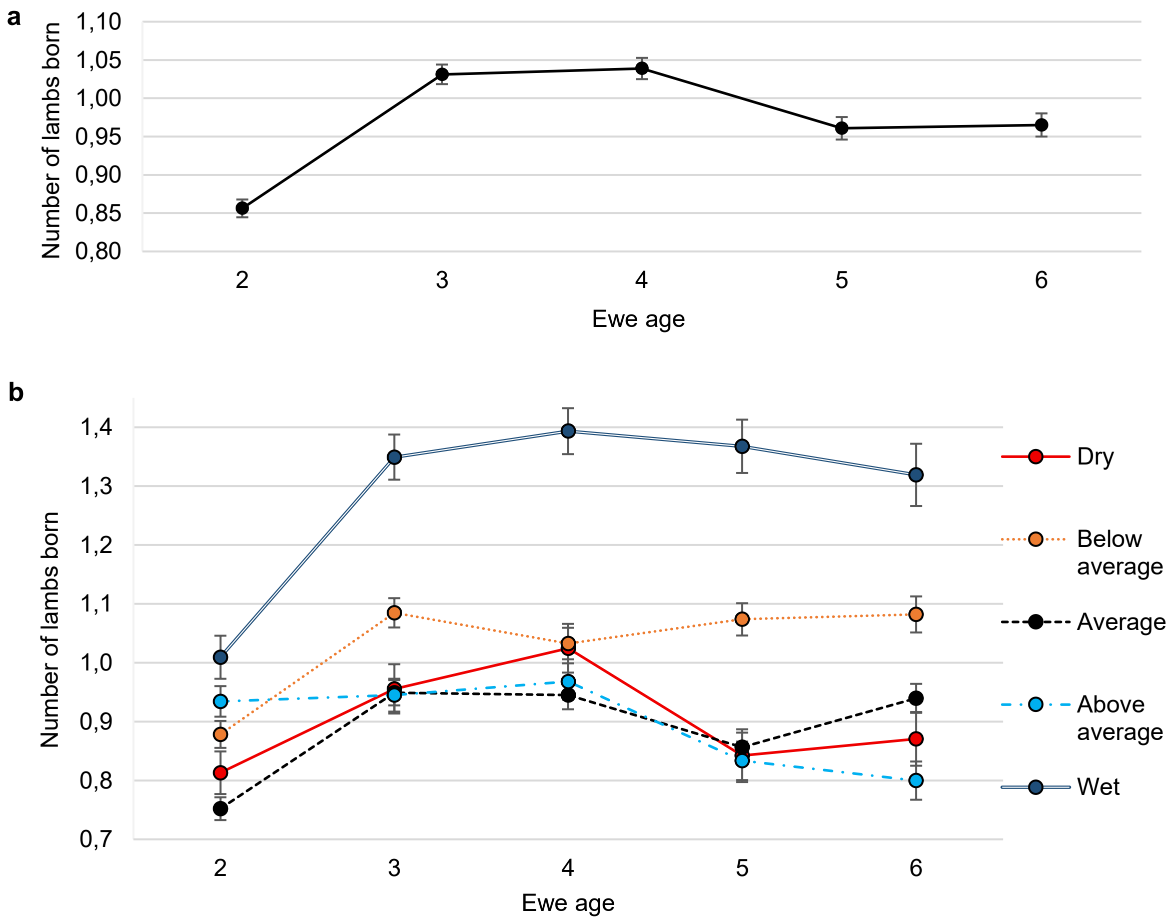
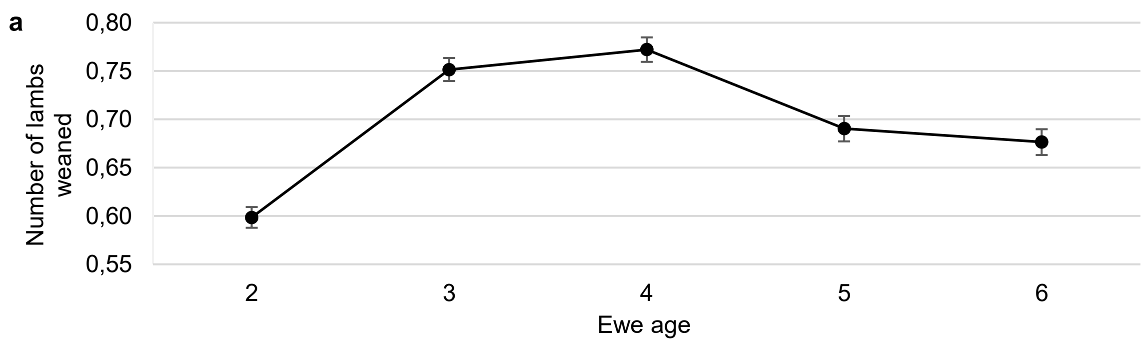


Figure 2 Effect of ewe age (in years) on the number of lambs born (mean ± standard error) in the Tygerhoek Merino flock, on average (**a**), and across the different rainfall classes (**b**).

The NLW increased to a peak value in four-year-old ewes, and then declined, although six-year-olds still had higher NLW values than maiden ewes (Figure 3a). This same trend was largely seen in all the rainfall classes, although slight differences were found (Figure 3b). In average and above-average rainfall seasons, there was a slight increase between five and six years of age, while the NLW in below-average seasons peaked at three years of age.



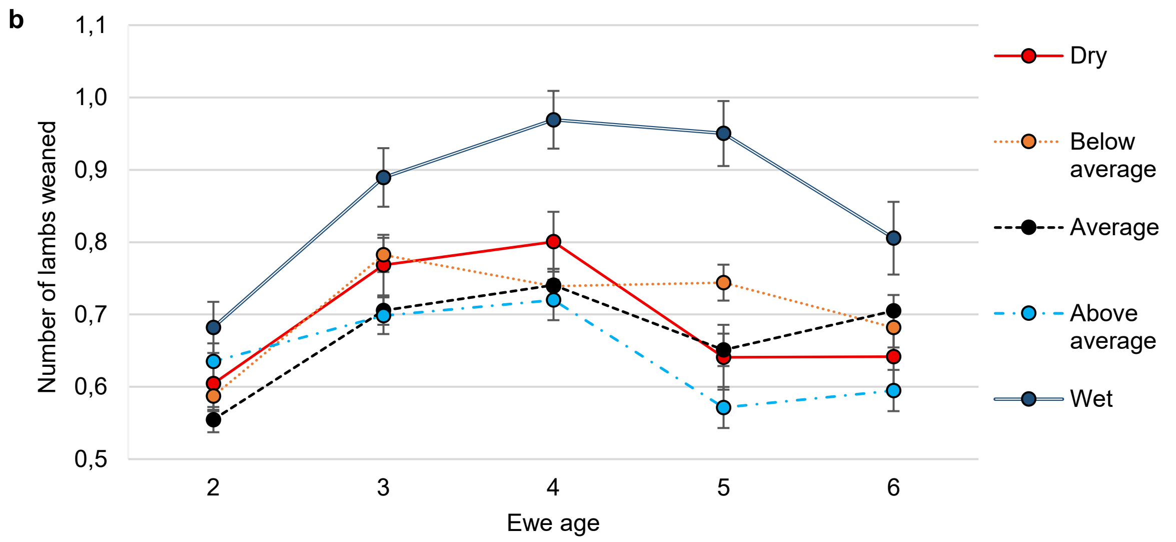


Figure 3 Effect of ewe age (in years) on the number of lambs weaned (mean ± standard error) in the Tygerhoek Merino flock, on average (**a**), and across the different rainfall classes (**b**).

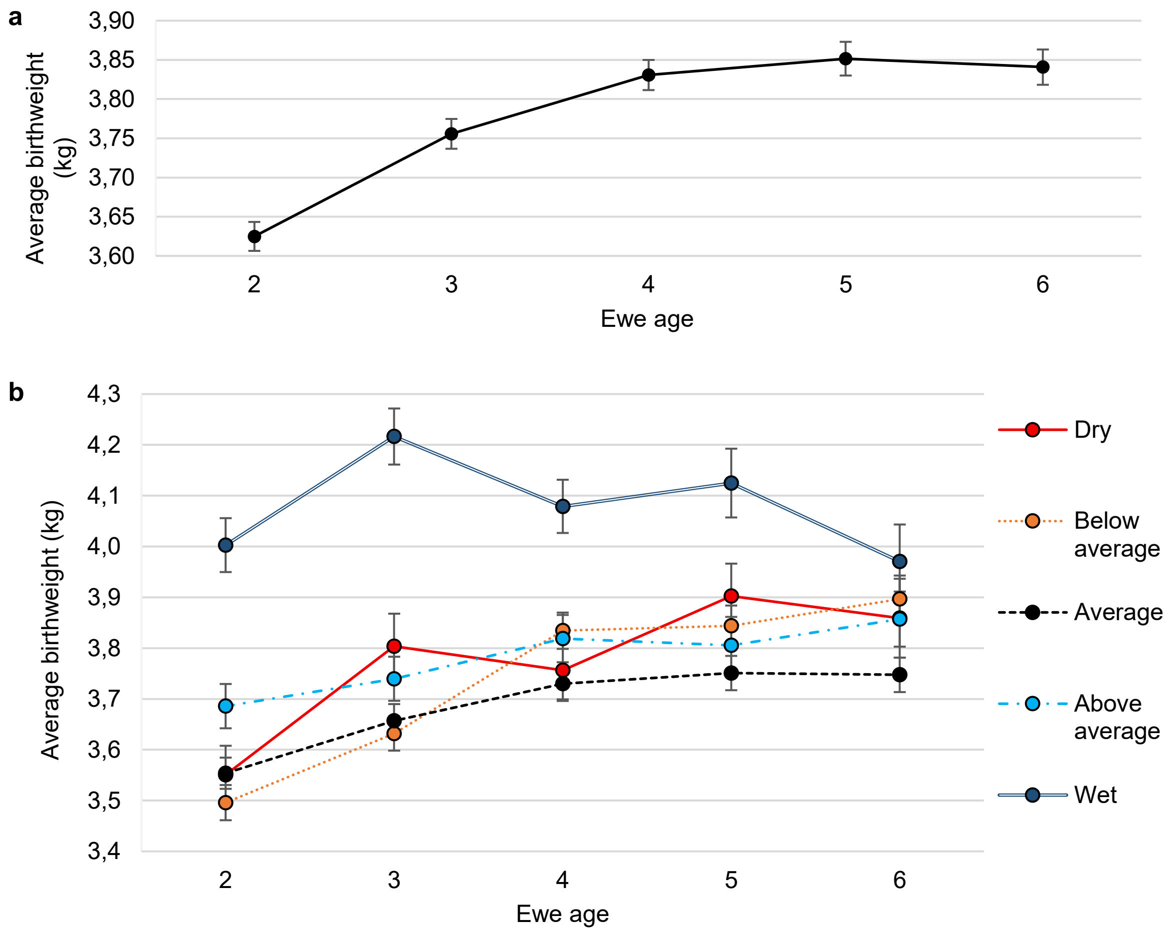


Figure 4 Effect of ewe age (in years) on the average birthweight (mean ± standard error) in the Tygerhoek Merino flock, on average (**a**), and across the different rainfall classes (**b**).

In Figure 4a, it can be seen that the ABW increased constantly with ewe age and peaked in four- to six-year-old ewes. This trend was mirrored in the below-average, average, and above-average rainfall seasons (Figure 4b). In wet seasons, the ABW peaked when the ewes were three years of age and declined thereafter, while in dry seasons it peaked in five-year-old ewes, but no significant differences existed from three to six years of age.

Overall, the AWW peaked in three-year-old ewes, stayed fairly constant until five years of age, and dropped sharply at six years of age, to the same level as in primiparous ewes (Figure 5a). This trend was followed in wet and above-average rainfall seasons, although six-year-olds showed lower values than maiden ewes in wet seasons (Figure 5b). In average seasons, a slow decline was observed with age, which was mirrored in below-average seasons. In dry seasons, there was a marked increase in the AWW until five years of age, when it plateaued. Performance in all these traits was highest in wet seasons, with little or no differences among the other rainfall classes.

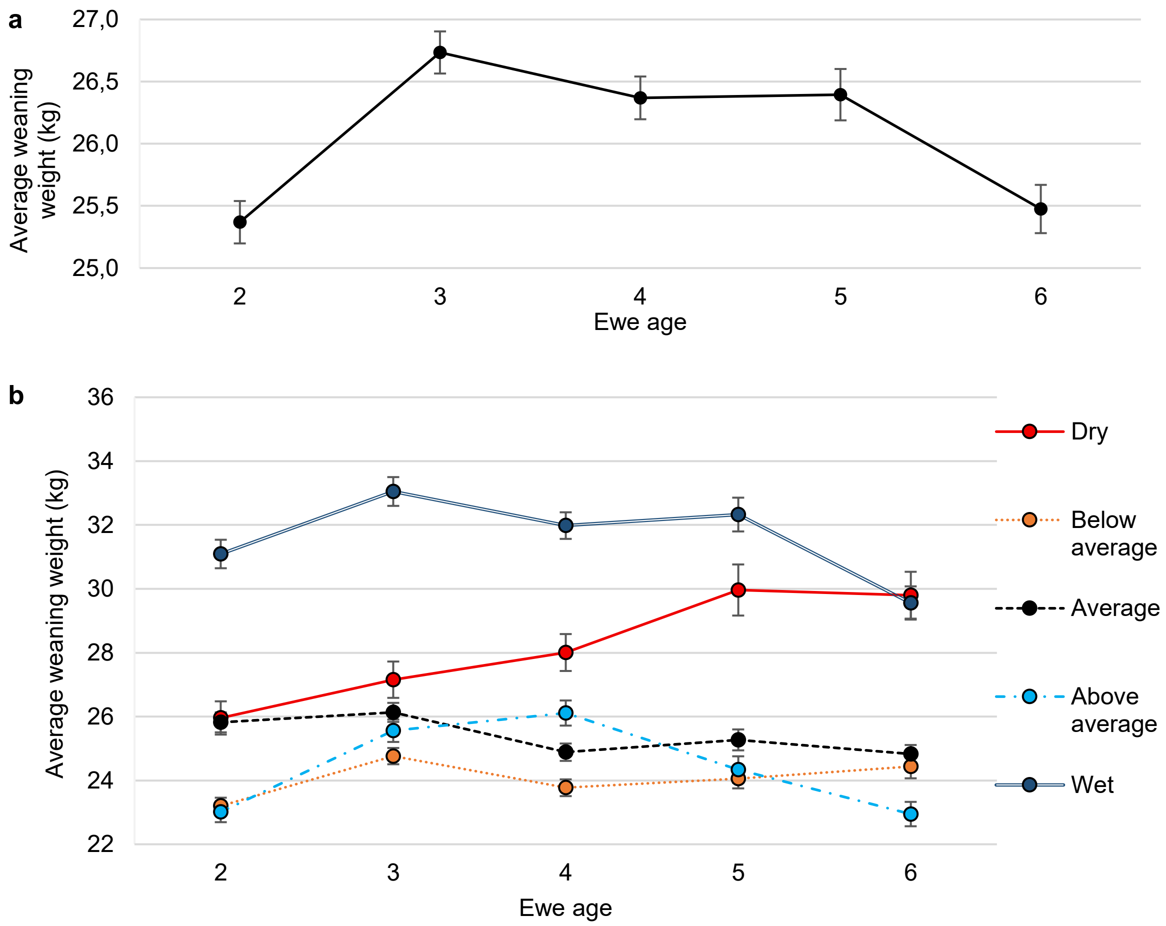


Figure 5 Effect of ewe age (in years) on the average weaning weight (mean ± standard error) in the Tygerhoek Merino flock, on average (**a**), and across the different rainfall classes (**b**).

Discussion

The effect of age on reproduction is well-documented in sheep (Aktaş *et al.*, 2015; Shorten *et al.*, 2021; Pettigrew *et al.*, 2021; Hutchison *et al.*, 2022; Nel *et al.*, 2022; Myrtill *et al.*, 2023) and the results obtained across all years in this study concurred with the general trends seen in the literature.

Conception rate was lowest in maiden ewes, peaked at three years of age, and declined thereafter to similar levels as in first-time lambers by five and six years of age. Similar trends were seen for NLB and NLW, except that performance did not decline to the same level as in maiden ewes after peaking in three- to four-year-old ewes. Overall, it is therefore clear that two-year-old ewes had the lowest reproductive performance. This concurs with the findings of numerous previous studies. Nel *et al.* (2022) reported lower conception rates in maiden ewes and optimal reproductive performance between three and four years of age across multiple Merino flocks, while previous work performed on this flock (Cloete & Heydenrych, 1986) also indicated an increase in conception rate with age. In the latter case, however, conception values stayed constant between three and six years of age, in contrast to the current findings. The current study was conducted on data collected over a longer time period, which may explain this difference.

The NLB has also been found to be lower in maiden ewes than in mixed-age flocks (Edwards & Juengel, 2017; Pettigrew *et al.*, 2021; Hutchison *et al.*, 2022). In this study, three- and four-year-olds produced the most lambs per ewe mated, followed by five- and six-year-old ewes, while two-year-olds had the lowest NLB values. This trend is almost universally supported in the literature across several breeds. Both Cloete *et al*. (2021) and Geerkens (2022) reported a similar trend in Dohne Merinos, while it has also been reported in Merinos (Cloete & Heydenrych, 1986; Aktaş *et al.*, 2015) and South African Mutton Merinos (Geerkens, 2022). However, some studies have contradicted these findings in Merinos, with Mullaney & Brown (1969) reporting a steady decline in the NLB as ewes aged, and Myrtill *et al*. (2023) finding no significant age effect.

There is obviously a correlation between the NLB and NLW under ordinary production conditions, and this explains why the same pattern as described above for the NLB was found for the NLW. As expected, this is again well-supported by available literature, with several studies reporting similar trends (Mullaney & Brown, 1969; Edwards & Juengel, 2017; Cloete *et al.*, 2021). Further studies also differentiated between the weaning performance of maiden and mature ewes and found that mature ewes performed better, partially because of improved lamb survival rates (Shorten *et al.*, 2021; Pettigrew *et al.*, 2021; Hutchison *et al.*, 2022). Nonetheless, Aktaş *et al.* (2015) found no difference in lamb survival between various dam age groups.

Lamb survival is largely dependent on birthweight (Everett-Hincks & Dodds, 2008). In this study, birthweight was found to increase with ewe age until four years of age, whereafter it remained constant. In Anatolian Merino ewes, there was an increase in birthweight between two- and three-year-old ewes, whereafter it remained fairly constant (Aktaş *et al.*, 2015). It was also reported that maiden Romney ewes delivered lighter lambs than mature ones (Corner *et al.*, 2013; Pettigrew *et al.*, 2021). It is therefore clear that primiparous ewes tend to deliver lighter lambs, regardless of breed or environment.

Finally, the AWW was compared across all seasons. It peaked at three years of age and remained constant until five years of age, whereafter it declined to similar levels as in two-year-olds. The lower AWW in maiden ewes is likely a result of the lower birthweights of lambs produced by these ewes, while the decrease in AWW in six-year-old ewes could be a result of the older ewes being unable to produce sufficient milk to enable their lambs to grow optimally. A similar trend was reported across various New Zealand industry flocks by Shorten *et al.* (2021), although weaning weights started to decrease at a younger age in that study. Ewes in the study reported by Aktaş *et al.* (2015) weaned the heaviest lambs at five years of age and the lightest at two years of age, while ewes of all other ages produced lambs with intermediate weaning weights. The trend of maiden ewes weaning lighter lambs is also supported by the work of Corner *et al.* (2013).

With the overall trends of each of the reproduction traits being clarified, the effects of rainfall class on those trends could be studied. Since a breeding flock's efficiency is strongly affected by the age structure of the animals in the flock (Turner & Young, 1969), as can also be deduced from the results presented above, it follows that the age structure becomes even more important under adverse environmental conditions when production outputs are placed under pressure. Ideally, the majority of the breeding animals in the flock should be of optimal reproductive age, in this case, three or four years old. However, it is not a given that these animals will also perform best during unfavourable rainfall seasons. A comparison between their overall performance and performance during each of the rainfall classes is thus warranted, as this will indicate which animals are best adapted to which rainfall scenarios. This information will allow producers to pre-emptively change the age profile of their flocks or reduce flock numbers in order to better mitigate the effects of unfavourable environmental conditions such as droughts.

Performance in all traits tended to be higher in wet seasons, but no clear differences emerged between the other rainfall classes. Conception relative to age remained largely unaffected by rainfall. In dry seasons, which are most likely to be of concern to producers, conception values peaked at three and four years of age. Peak conception rates overall were in three-year-old ewes; therefore no marked difference existed. Conception rates in below-average rainfall seasons also peaked in three-year-old ewes and remained fairly constant thereafter. Average seasons followed the overall trend, as did wet seasons. Thus, conception in this flock can be regarded as being unaffected by rainfall.

The overall trend for the NLB was largely followed across all rainfall classes. Minor differences were present in some cases, but in general no age group deviated markedly from the overall trend. The same held true for the NLW. The age effects affecting the three traits that determine overall reproductive performance are therefore largely independent of rainfall. This means that a flock structured to maximise these three traits will best adapt to a variety of environmental conditions, and producers do not need to modify the age structure of their flocks during unfavourable seasons.

Birthweight, as in the overall analysis, increased with age in all rainfall classes except in wet seasons. In wet seasons, it followed no clear trend, peaking at three years of age and having the absolute lowest value at six years of age. However, the ABW in six-year-old ewes was only significantly lower than the peak value in three-year-old ewes. It could be speculated that the environmental conditions in wet seasons were so favourable that they allowed younger animals to essentially overcome the age effect seen in all other seasons and increase their ABW, but it is unclear as to why that would not also affect the oldest ewes. This could potentially be explored further in future studies.

Unexpectedly, the AWW increased with age in dry seasons. The other rainfall classes largely followed the overall trend, where AWW was highest between three and five years of age and lower in two- and six-year-olds. The improvement in dry seasons may have been due to older ewes having more experience in foraging and selecting the best grazing to maintain their body condition and milk production so as to benefit their lambs. However, further work needs to be done to corroborate this finding before it can be unequivocally accepted.

It can be concluded from these trends that no age group is better suited to reproduce under specific rainfall conditions than it is to reproduce under varying levels of rainfall. The only exception to this can be seen in the AWW, where older ewes appear to perform better in dry seasons. However, since no other trait shows a similar affinity for dry seasons, producers will be unable to leverage this improvement by modifying the age structure of their flocks, since the improved weaning weights will be offset by the age-linked decline in reproduction.

Although this study should be replicated in other breeds and locations in order to verify the results presented here, the length of time over which data were collected and the number of individuals in the dataset lends credence to the trends observed and makes it highly likely that the results and conclusions are accurate and will be repeatable.

Conclusion

Age significantly affected all traits included in this study, with three- and four-year-old ewes having the highest reproduction rates. Based on this, it would be advantageous for Merino producers to maintain flocks where the majority of ewes are at this optimal age for reproduction. The effect of age on reproduction is independent of rainfall in the preceding production season, meaning that flock age structure cannot be manipulated to mitigate the effects of droughts or other variations in rainfall if the age profile of the flock is already optimised for reproduction. Producers who already have a flock that is structured to optimise reproduction would therefore have no reason to modify the age structure of their flocks.

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Authors' contributions

P.G.T. was responsible for conceptualisation, data preparation and analysis, interpretation of results, and writing of the manuscript. T.S.B. and S.W.P.C. obtained funding and data access, respectively, and supervised the project and were involved in the writing and editing of the manuscript. J.H.C.v.Z. contributed to supervision and editing. All the authors were involved in the finalisation of the manuscript and all the authors have read and approved the final manuscript.

Conflict of interest declaration

No conflicts of interest have been identified with this study. The opinions, findings, and conclusions in this study are those of the authors and do not necessarily reflect those of any of the funders.

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