South African Journal of Animal Science 2026, vol. 56(5)

Risk factors for non-adapting weaner lambs entering South African feedlots

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(Submitted 20 September 2025; Accepted 04 May 2026; Published 12 May 2026)

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Abstract

A growing concern in South African feedlot systems is the increased prevalence of non-adapting weaner lambs. This study aimed to identify on-farm risk factors associated with poor adaptation using retrospective production data and a structured questionnaire administered to 80 lamb-rearing farms across South Africa. Risk factors were estimated using Poisson regression to calculate risk ratios and 95% confidence intervals. Of the farmers interviewed, 56% (45/80) did not supply creep feed to their pre-weaned lambs in any form, whereas 75% (60/80) supplied additional feed to their ewes. A lack of creep feed supplementation, extensive lamb rearing, and lambs being born in seasons other than summer were significant risk factors for non-adapting lambs. Spatial clustering of high-death locations was also observed. Creep feeding offers critical benefits, including improved rumen development, increased weight gain, earlier weaning, and improved feedlot adaptability. Lamb-producing areas in South Africa occur in semi-arid regions with low carrying capacities, favouring extensive management systems. Creep feed is often infrequently offered or omitted in extensive rearing systems, owing to logistical challenges. The weaner lamb price, typically determined by feedlots, is rarely influenced by on-farm managerial practices such as creep feed supplementation. As a result, producers may view creep feeding as an unnecessary expense, because of the lack of financial incentives. Promoting awareness of the production and economic benefits of creep feeding, improving communication between feedlots and lamb producers, and encouraging the implementation of good agricultural practices would encourage farmers to adopt specified production and management practices to improve lamb adaptability in South African feedlots.

Keywords: creep feed, poor-doers, Poisson regression, rumen development

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URL: www.sajas.co.za
ISSN 0375-1589 (print), ISSN 2221-4062 (online)
Publisher: South African Society for Animal Science
https://doi.org/10.17159/sajas.v56i05.01

Introduction

The world sheep population is approximately 1.36 billion head (Food and Agriculture Organization of the United Nations, 2025), with the major sheep farming areas located between 35 and 55 degrees north in Europe and Asia, and between 30 and 45 degrees south in South America, Australia, and New Zealand (Morris, 2017). Sheep production is important in subtropical climates, including Australia, Brazil, China, South Africa, Spain, and Uruguay (Poli *et al.*, 2020), with both temperate and tropical pastures in overlapping seasons providing year-round forage (Poli *et al.*, 2020).

Weaner lambs can be raised on pasture, which has a low input cost; however, the seasonal availability of pastures and risk of internal parasite infestations (Tontini *et al.*, 2019) make pasture finishing a risky and unreliable proposition (Meat and Livestock Australia, 2020). Alternatively, weaner lambs can be raised more intensively, in feedlots, in an attempt to produce a carcass of optimal weight and fat coverage for maximal income (Van der Merwe *et al.*, 2020).

Feedlot systems create high stress for weaner lambs (Navarro *et al.*, 2019). Upon arrival at the feedlot, lambs from different farms are often grouped in pens (co-mingled), potentially exposing animals to health risks and behavioural stressors (Cooke, 2017). Ovine respiratory complex (Gonzalez *et al.*, 2016) is one of the primary diseases affecting lambs in many countries (Navarro *et al.*, 2019), and is associated with laboured breathing, pyrexia, nasal discharge, and coughing (Alley, 2002; Bell, 2008). Sudden changes in diet, particularly increasing the plane of nutrition and feeding readily fermentable carbohydrates, can lead to enterotoxaemia caused by *Clostridium perfringens* type D exotoxins (Wise, 1957), as well as ruminal acidosis (Fanning *et al.*, 2018). Weaner lambs are at risk of developing ruminal acidosis despite the mechanisms being relatively well understood and adaptation methods for the safe transition of lambs to grain-based diets being available (Bowen *et al.*, 2006).

Creep feeding, a pre-weaning nutrition strategy in livestock management, supplies young animals with readily fermentable carbohydrates that promote starch fermentation and decreased rumen pH, fostering bacterial growth for increased butyrate production and rumen papillary development (Warner & Flatt, 1964). The omission of creep feed might delay rumen development, leading to compromised lambs arriving at feedlots that are unable to adapt to these rations. Creep feeding promotes the establishment of ruminal fermentation, leading to both the physical and metabolic development of the rumen (Baldwin *et al.*, 2004), which could help improve the adaptation of lambs to grain-based diets.

Parasitic and infectious conditions can also compromise lamb development and health. *Haemonchus contortus* causes severe anaemia, weight loss, and abomasal lesions, while lambs infected with *Cryptosporidium parvum* exhibit significant small intestinal damage, hindering nutrient digestion and absorption (Angus *et al.*,1982; Delano *et al.*, 2002; Carioto, 2014; Flay *et al.*, 2022). Decreased milk intake and reduced nutrient digestion and absorption in lambs could potentially induce a catabolic, cachectic, and hypothermic state, negatively affecting rumen development by hindering rumen microbial colonisation. Triplet-born lambs have lower rectal temperatures at birth, reduced colostrum intake, and placental insufficiency, making them more susceptible to metabolic compromise, which may also delay rumen development (Barlow *et al.*, 1987; Dwyer *et al.*, 2005).

These risk factors highlight common challenges faced by sheep farmers globally, including factors and conditions that could predispose suckling lambs to metabolic compromise before weaning. While previous studies have examined the growth, survivability, and health of lambs prior to weaning, limited research has been done regarding flock-level risk factors associated with non-adaptation in feedlot environments, highlighting a critical knowledge gap.

Another potential risk factor is inappetence, or shy feeding, with lambs not adapting to the feedlot environment. This behaviour cannot be predicted by feedlot operators, researchers, or feedlot consultants (Keogh *et al.*, 2021). Non-adapters or poor-doers typically present with lethargy, dullness, and depression, and have a severely indented left paralumbar fossa, indicating poor feed consumption. Globally, an estimated 5% to 20% of sheep entering feedlots fail to adapt to both the feed and the environment (Kirby *et al.*, 2004; Jolly & Wallace, 2007).

Inappetence/shy feeding leading to the maladaptation of lambs is believed to be caused by neophobia (a fear of anything new) towards feed and the environment (Savage *et al.*, 2008), as well as competition with other animals for feeding space (Rice *et al.*, 2016). Neophobia is a persistent problem in both the live export industry and intensive lamb finishing systems (Jolly & Wallace, 2007). Another potential stressor leading to maladaptation is transport stress, which can be induced by long transport

durations, high environmental temperatures, poor road conditions, and high stocking densities on transportation vehicles (Fisher *et al.*, 2005; Rioja-Lang *et al.*, 2019; Goetz *et al.*, 2022).

The combination of transport stress, change in environment, and shift in social hierarchy among lambs in feedlot pens might lead to certain lambs not adapting to feedlot conditions and being classified as 'poor-doers'. These non-adapting lambs often require special attention and management to ensure survival, such as separating vulnerable animals and placing them in a pen with a lower stocking density (Davis, 2003), or placing them onto pastures or fodder crops to reduce social stress (Duddy *et al.*, 2016).

It was hypothesised that lambs from flocks where creep feed was excluded, flocks with ineffective control of neonatal *H. contortus* and *C. parvum* infections, and flocks with a high incidence of twins and triplet births would have an increased prevalence of non-adapting weaner lambs. The objective of this study was to estimate flock-level risk factors for non-adapting lambs entering South African feedlots.

Materials and methods

The study was conducted across lamb-rearing farms within South Africa. Lamb-rearing farms were located in the Free State (28.4541°S, 26.7968°E; predominantly grassland and Nama Karoo biomes), Northern Cape (29.0467°S, 21.8569°E; Nama Karoo biome), Western Cape (33.2278°S, 21.8569°E; fynbos biome), Eastern Cape (32.2968°S, 26.4194°E; a combination of thicket, savannah, and grassland biomes), Mpumalanga (25.5653°S, 30.5279°E; grassland biome), Kwa-Zulu Natal (28.5306°S, 30.8958°E; savannah biome), and Gauteng (26.2708°S, 28.1123°E; predominantly grassland biome). The climate of these areas ranges from a Mediterranean type in the Western and Eastern Cape to a semi-arid and semi-desert climate in the Northern Cape and Free State provinces (Red Cross Climate Centre, 2021).

Sheep farming is practiced throughout the country but is more common in the arid regions (Department of Agriculture Land Reform and Rural Development, 2021). A total of 80 farmers from seven provinces spread across South Africa were selected for questionnaire administration and the collection of production data. These 80 farms were distributed across the following provinces: Gauteng (1/80), Free State (27/80), Kwa-Zulu Natal (2/80), Mpumalanga (2/80), Northern Cape (25/80), Eastern Cape (22/80), and Western Cape (1/80).

The study protocol was approved by the Research and Animal Ethics Committee of the Faculty of Veterinary Science at the University of Pretoria (reference: REC019-24). In addition, ethical clearance for research involving human participants (questionnaire administration) was obtained from the Faculty of Humanities, University of Pretoria (reference: HUM 027/0524). All personal information disclosed by farmers during the completion of the questionnaire was handled in strict confidence.

The sample size was calculated using Open-Source Epidemiologic Statistics for Public Health (Kelsey *et al.*, 1996) (https://www.openepi.com), assuming a 20% prevalence of disease in the unexposed group, an estimated odds ratio of four, equal group sizes for a dichotomised risk factor, an alpha error rate of 5%, and a power of 80%. The calculated sample size was 80 farms to achieve statistical significance. For traceability purposes and because of the threat of certain controlled diseases currently present in South Africa, feedlots keep records of all lamb suppliers (specifically their geographical location) when receiving lambs into their feedlots. Based on these supplier lists, simple random sampling was used to select lamb-rearing farms to participate in the study.

Farm visits were scheduled and questionnaires administered by the principal author over an approximately 11-week period (June to August 2024). Lamb batches from selected lamb-rearing farms completed their 60-day feedlot production cycles across several feedlots between March and June 2024. On average, 20 days elapsed between post-slaughter data collection for a batch of lambs and the administration of the questionnaire to the respective lamb supplier. Farm locations were also mapped to the nearest municipality to evaluate the spatial clustering of disease.

Risk factor information was collected using a questionnaire. The questionnaire consisted of five sections: feed management and nutrition, rearing system and pasture management, disease control, internal parasite control, and production parameters (questionnaire available on request from the author). The questionnaire was pre-tested with a pilot study among commercial lamb producers in Bothaville, Free State Province, during a farmers' day (n = 7), and questions were modified for clarity based on the pre-test results. Farmers involved in the pre-testing were not eligible for inclusion in the study. The questionnaire was administered in person to farm managers or owners who agreed to

participate after providing informed consent (consent form available on request from the author). The consent form, which explained the background and overall aim of the research, was reviewed with each participant prior to questionnaire completion.

Participants were recruited telephonically, and farm visits were scheduled to facilitate questionnaire administration. Interviews were conducted in English or Afrikaans according to the farmer's preference and took approximately 15–20 minutes to complete. The principal author's bilingual proficiency in both languages facilitated clear communication throughout the interview process. Questionnaires were completed manually, and the data were subsequently entered electronically into an Excel spreadsheet (Excel 2007; Microsoft Corp., Redmond, WA, USA). Access to the dataset was restricted to the research team, and all data were handled confidentially.

Weaner lambs supplied to feedlots were separated into supplier-specific batches to ensure traceability, as well as to measure morbidity and mortality rates, live feedlot performance, and carcass characteristics for lambs from each supplier. Feedlots monitor these factors so that they can continuously identify and source lambs from suppliers whose lambs perform well under feedlot conditions. When a batch of lambs originating from a lamb producer selected by simple random sampling was slaughtered, morbidity and mortality data were extracted from feedlot records. The time interval from batch data collection post-slaughter to questionnaire administration was recorded and was mainly influenced by farmer availability.

For descriptive presentation, farms were classified into two categories: high mortality (affected) and low mortality (unaffected), based on the median mortality proportion of selected lamb batches. Risk factors for non-adapting lambs and general lamb mortality rates were estimated using Poisson regression, yielding risk ratios (RR) and 95% confidence intervals (95% CI). Evaluated outcomes were the number of mortalities with evidence of non-adaptation (poor body condition score and poor rumen fill) at necropsy out of the total number of lambs in the batch, and the overall mortality rate (number of deaths out of total batch size).

Univariate models were used initially to screen potential risk factors, and Spearman's rank correlation coefficient (rho) was used to assess collinearity among potential predictors. Variables with Spearman's rho >0.7 or <−0.7 were considered collinear, and only the variable with the strongest apparent association with the outcome was retained for multivariable modelling. For exposures with multiple codings, a single variable was selected for inclusion in the multivariable model (because of collinearity), with the remaining related variables accounted for through this choice. All non-collinear variables with Wald *P*-values of <0.2 were included in the multivariable Poisson regression model.

Multivariable analyses were performed using a backward elimination approach through the removal of variables with the largest Wald *P*-values. Variables were excluded systematically, one-by-one, until only variables with *P*-values of less than 0.05 ($P < 0.05$) remained. Statistical analysis was conducted using commercial software (IBM SPSS Statistics version 29; International Business Machines Corp., Armonk, NY, USA). Spatial clustering was evaluated using the Cuzick-Edwards test (Cuzick & Edwards, 1990), considering only the first nearest neighbour.

Farms were geolocated to the nearest municipality and average mortalities were calculated for municipalities with more than one farm. Median values were used to classify municipalities as high (greater than the median) or low mortality. The determination of nearest neighbours and calculation of the test statistic were performed in a spreadsheet (Excel 2007; Microsoft Corp., Redmond, WA, USA). Statistical results were interpreted at a 5% level of significance.

Results

There was significant spatial clustering of high-death locations, based on the Cuzick-Edwards *Z*-score (Z) of 2.62 ($P = 0.009$). The pins in the legend (Figure 1) represent the nearest large town to the sampled farms.

Of the 80 farmers who completed the questionnaire, 56% (45/80) did not supply creep feed to their pre-weaned lambs (Table 1). The remaining 44% (35/80) of producers provided creep feed to their lambs using various methods, including buckets, feed gates, or other feeding systems. With regards to the nutritional supplementation of the ewes on the sampled farms, 75% (60/80) supplied feed in the form of a total mixed ration or pelleted ration to their lactating ewes, whereas 25% (20/80) did not provide additional feed supplementation during lactation.

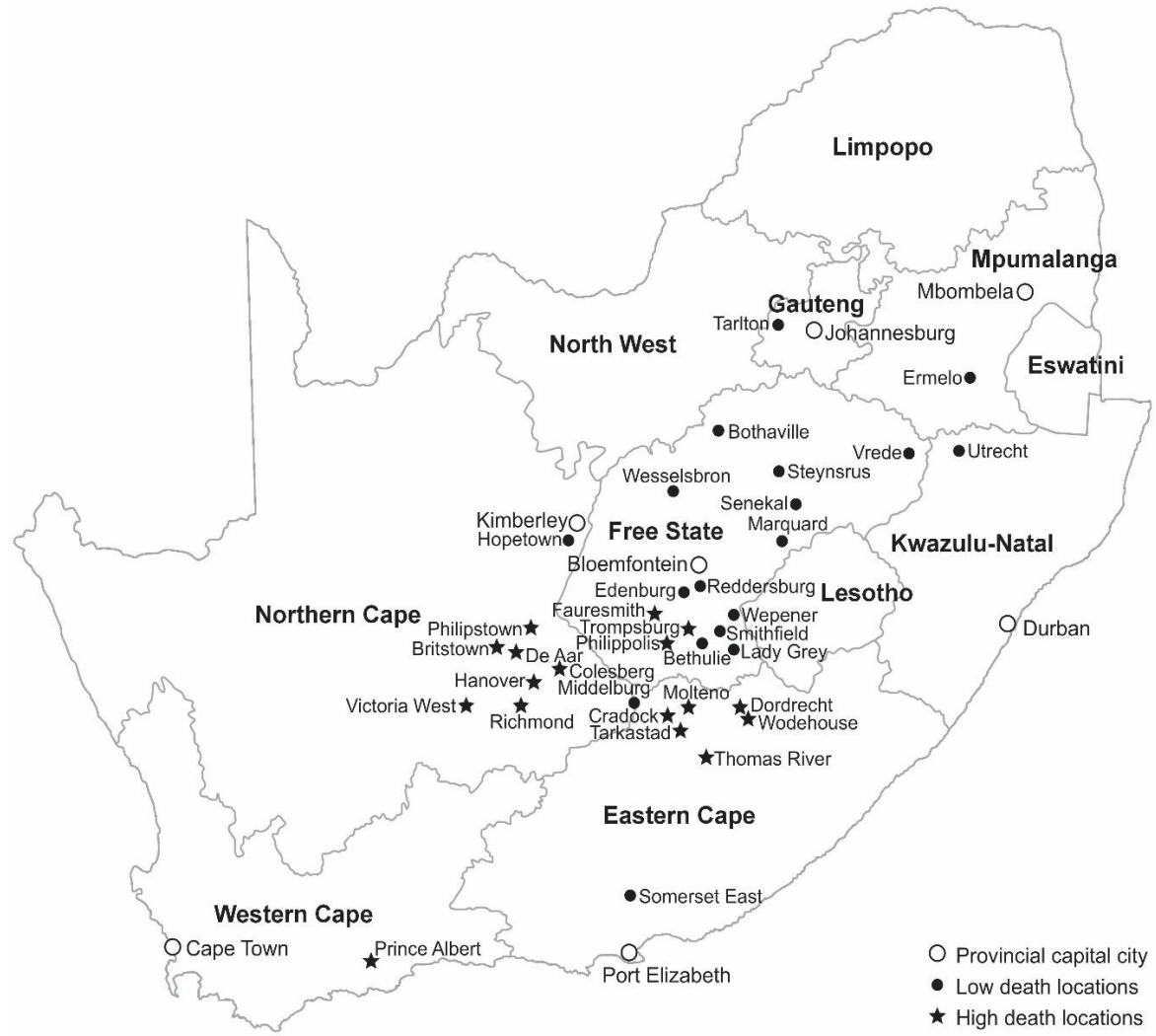

Figure 1 Distribution map of high (n = 17) and low (n = 18) death locations in which lamb producers completed the questionnaire (June–August 2024).

A lack of creep feed supplementation, a lack of intensive or semi-intensive rearing, the use of extensive rearing systems, lambs not raised in summer, lambs not raised in winter, a lack of routine vaccinations against pneumonic pasteurellosis and chlamydiosis, and flocks with fewer than 30% twins were significantly associated with non-adapting lambs on univariate analysis (Table 2). In the final multivariable model (Table 3), a lack of creep feed supplementation (RR: 3.33, 95% CI: 1.98–5.60, P <0.001), extensive lamb rearing (RR: 2.57, 95% CI: 1.37–4.82, P = 0.003), and lambs not raised during the summer (RR: 2.59, 95% CI: 1.05–6.40, P = 0.039) remained significant risk factors for non-adapting lambs arriving in South African feedlots.

Table 1 South African sheep farmers' (n = 80)[1] responses to a questionnaire on applied management practices[2]

Variable	Response	Number of farms	% of farms	Definition
Creep feed supplied to lambs before weaning:				
	Yes	35	44	A readily fermentable, nutrient-dense feed is supplied to lambs prior to weaning.
	No	45	56	A readily fermentable energy-dense feed is not supplied to lambs prior to weaning.
Ewe supplemented with feed during lactation:				
	Yes	60	75	Ewes are supplemented with feed when they have a lamb at foot.
	No	20	25	Ewes are not supplemented with feed when they have a lamb at foot.
Rearing system used on farm:				
	Intensive	7	9	Ewes give birth in crates, and the ewe and lamb(s) remain in a small pen, separate from other ewes and lambs.
	Semi-intensive	13	16	The ewe and lamb walk outside during the day and are penned at night together with other ewes and lambs.
	Extensive	60	75	Ewes give birth in the veld and the ewe and lamb live outdoors without being penned at night.
Water source on farm:				
	Dam	26	33	Water is provided from a dam.
	Borehole	74	93	Water is provided from a borehole.
	River/stream	24	30	Water is provided from a river/stream.
Ewes routinely vaccinated on an annual basis:				
	Yes	78	98	Ewes are vaccinated annually.
	No	2	2	Ewes are not vaccinated annually.
Strategies in place to prevent worm infestations:				
	Yes	77	96	Strategies are in place to prevent worm infestations.
	No	3	4	No strategies are in place to prevent worm infestations.

[1] Farmers located across the major lamb-producing provinces of South Africa were interviewed from June to August 2024. [2] Management practices examined included the nutritional management of ewes and lambs, the type of rearing system, the farm water source, and disease and parasite control measures.

Table 2 Univariate analysis of factors associated with lambs not adapting to feedlots, as found among commercial lamb producers (n = 80) across the major lamb-producing provinces of South Africa in 2024

Variable	Level	No. farms	Crude mortality	Slope parameter	Risk ratio (95% CI)	*P*-value
Creep feed supplied to lambs before weaning:	No	35	0.052	1.501	4.49 (2.78–7.25)	<0.001
	Yes	45	0.012	Referent	-	-
Creep feed composition:	Not applicable	35	0.052	1.453	4.28 (2.14–8.54)	<0.001
	Commercial feed	30	0.011	−0.070	0.93 (0.45–1.92)	0.849
	Self-mixed ration	15	0.012	Referent	-	-
Amount of creep feed allocated per lamb:	Not applicable	35	0.052	1.619	3.98 (2.32–6.82)	<0.001
	Limit fed	16	0.009	−0.374	0.69 (0.34–1.39)	0.3
	Ad libitum	29	0.013	Referent	-	-
Age at which creep feed was supplied:	Not applicable	35	0.052	1.619	5.05 (2.50–10.20)	<0.001
	Birth to weaning	6	0.004	−1.009	0.37 (0.10–1.28)	0.115
	2 weeks to weaning	24	0.014	0.326	1.39 (0.65–2.96)	0.399
	1 month to weaning	15	0.01	Referent	-	-
Creep feed supplementation method:	Not applicable	35	0.052	1.263	3.54 (1.78–7.04)	<0.001
	Feed gates	32	0.01	−0.364	0.70 (0.34–1.43)	0.325
	Bucket	13	0.015	Referent	-	-
Ewe supplemented with feed:	No	20	0.041	0.489	1.63 (0.96–2.78)	0.072
	Yes	60	0.025	Referent	-	-
Ewe feed composition:	Not applicable	20	0.041	0.762	2.14 (1.04–4.43)	0.039
	Commercial feed	44	0.027	0.349	1.42 (0.75–2.70)	0.288
	Self-mixed ration	16	0.019	Referent	-	-
Amount of feed allocated per ewe:	Not applicable	20	0.041	0.134	1.14 (0.55–2.36)	0.717
	Limited amount	46	0.022	−0.485	0.62 (0.32–1.17)	0.138
	Ad libitum	14	0.036	Referent	-	-

No.: number, CI: confidence interval.

Table 2 (continued)

Variable	Level	No. farms	Crude mortality	Slope parameter	Risk ratio (95% CI)	*P*-value
Intensive rearing system on farm:	No	73	0.032	1.936	6.93 (2.57–18.66)	<0.001
	Yes	7	0.005	Referent	-	-
Semi-intensive rearing system on farm:	No	67	0.033	1.096	2.99 (1.54–5.81)	0.001
	Yes	13	0.011	Referent	-	-
Extensive rearing system on farm:	No	20	0.009	−1.414	0.24 (0.14–0.43)	<0.001
	Yes	60	0.036	Referent	-	-
Free State:	No	52	0.031	0.221	1.247 (0.765–2.032)	0.375
	Yes	28	0.025	Referent	-	-
Northern Cape:	No	55	0.024	−0.571	0.565 (0.343–0.931)	0.025
	Yes	25	0.042	Referent	-	-
Eastern Cape:	No	58	0.031	0.206	1.228 (0.725–2.080)	0.445
	Yes	22	0.025	Referent	-	-
Arid/semi-arid:	No	27	0.022	−0.409	0.664 (0.403–1.094)	0.108
	Yes	53	0.033	Referent	-	-
Grassland:	No	29	0.037	0.414	1.513 (0.934–2.452)	0.093
	Yes	51	0.025	Referent	-	-
Lambing season occurred in summer:	No	71	0.032	1.216	3.04 (1.51–7.53)	0.003
	Yes	9	0.009	Referent	-	-
Lambing season occurred in winter:	No	63	0.032	0.578	1.78 (1.00–3.18)	0.05
	Yes	17	0.018	Referent	-	-
Irrigated pasture utilised on farm:	No	53	0.033	0.407	1.50 (0.91–2.48)	0.113
	Yes	27	0.022	Referent	-	-

No.: number, CI: confidence interval.

Table 2 (continued)

Variable	Level	No. farms	Crude mortality	Slope parameter	Risk ratio (95% CI)	*P*-value
Rotational grazing performed:	No	55	0.032	0.384	1.47 (0.88–2.46)	0.144
	Yes	25	0.022	Referent	-	-
Animals routinely vaccinated against pneumonic pasteurellosis:	No	29	0.042	0.664	1.94 (1.20–3.15)	0.007
	Yes	51	0.022	Referent	-	-
Animals routinely vaccinated against chlamydiosis:	No	66	0.033	0.894	2.45 (1.30–4.59)	0.005
	Yes	14	0.013	Referent	-	-
Diagnosis of *Cryptosporidium* made:	No	77	0.03	0.837	2.31 (0.68–7.82)	0.179
	Yes	3	0.013	Referent	-	-
Ewe deworming frequency against wireworm:	<4× per year	44	0.035	0.405	1.50 (0.94–2.39)	0.089
	>4× per year	36	0.023	Referent	-	-
Ewes dewormed with macrocyclic lactones:	No	46	0.034	0.354	1.42 (0.88–2.30)	0.147
	Yes	33	0.024	Referent	-	-
Lambs dewormed with macrocyclic lactones:	No	37	0.035	0.37	1.45 (0.91–2.32)	0.123
	Yes	42	0.024	Referent	-	-
Conception percentage measured:	No	29	0.039	0.481	1.62 (1.00–2.62)	0.051
	Yes	51	0.024	Referent	-	-
Lambing percentage measured:	No	34	0.035	0.334	1.40 (0.87–2.24)	0.164
	Yes	46	0.025	Referent	-	-
Weaning weight measured:	No	37	0.034	0.323	1.38 (0.87–2.21)	0.176
	Yes	43	0.025	Referent	-	-
Twins in flock:	<30%	50	0.034	0.572	1.77 (1.06–2.96)	0.029
	>30%	27	0.019	Referent	-	-

No.: number, CI: confidence interval.

Table 3 Multivariable analysis of factors associated with lambs not adapting to feedlots, as found among commercial lamb producers (n = 80) across the major lamb-producing provinces of South Africa in 2024

Variable	Level	No. farms	Slope parameter	Risk ratio (95% CI)	*P*-value
Creep feed (any):	No	35	1.202	3.33 (1.98–5.60)	<0.001
	Yes	45	Referent	-	-
Extensive rearing system on farm:	No	20	0.944	2.57 (1.37–4.82)	0.003
	Yes	60	Referent	-	-
Lambing occurring outside of summer:	No	71	0.953	2.59 (1.05–6.40)	0.039
	Yes	9	Referent	-	-

No.: number, CI: confidence interval.

A lack of creep feed supplementation, a lack of intensive and semi-intensive rearing, the use of extensive rearing, lambs not raised in summer, lambs not raised in winter, a lack of routine vaccinations against pneumonic pasteurellosis, and flocks with fewer than 30% twins were significantly associated with general lamb mortality on univariate analysis (Table 4).

In the final multivariable model (Table 5), both the lack of creep feed supplementation (RR: 2.40, 95% CI: 1.41–4.09, $P = 0.001$) and the use of extensive rearing conditions (RR: 1.93, 95% CI: 1.03–3.643, $P = 0.042$) were significant risk factors associated with general lamb mortality upon or soon after arrival at South African feedlots.

Table 4 Univariate analysis of factors associated with feedlot lamb mortality, as found among commercial lamb producers (n = 80) across the major lamb-producing provinces of South Africa in 2024

Variable	Level	No. farms	Crude mortality	Slope parameter	Risk ratio (95% CI)	*P*-value
Creep feed supplied to lambs before weaning:	No	35	0.065	1.056	2.87 (1.81–4.58)	<0.001
	Yes	45	0.023	Referent	-	-
Creep feed composition:	Not applicable	35	0.065	1.043	2.84 (1.48–5.44)	0.002
	Commercial feed	30	0.022	−0.020	0.98 (0.50–1.93)	0.954
	Self-mixed ration	15	0.023	Referent	-	-
Amount of creep feed allocated per lamb:	Not applicable	35	0.065	1.085	2.96 (1.75–5.00)	<0.001
	Limited amount	16	0.024	0.079	1.08 (0.56–2.09)	0.813
	Ad libitum	15	0.022	Referent	-	-
Age at which creep feed was supplied:	Not applicable	35	0.065	1.311	3.71 (1.90–7.24)	<0.001
	Birth to weaning	6	0.012	−0.397	0.67 (0.23–1.92)	0.469
	2 weeks to weaning	24	0.028	0.478	1.61 (0.79–3.30)	0.19
	1 month to weaning	15	0.017	Referent	-	-
Creep feed supplementation method:	Not applicable	35	0.065	0.963	2.62 (1.34–5.13)	0.005
	Feed gates	32	0.022	−0.134	0.88 (0.44–1.75)	0.704
	Bucket	13	0.025	Referent	-	-
Intensive rearing system on farm:	No	73	0.044	1.086	2.96 (1.26–6.99)	0.013
	Yes	7	0.015	Referent	-	-
Semi-intensive rearing system on farm:	No	67	0.045	0.890	2.44 (1.28–4.65)	0.007
	Yes	13	0.019	Referent	-	-
Extensive rearing system on farm:	No	20	0.017	−1.043	0.35(0.20–0.61)	<0.001
	Yes	60	0.049	Referent	-	-
Free State:	No	52	0.046	0.358	1.431 (0.884–2.316)	0.145
	Yes	28	0.032	Referent	-	-

No.: number, CI: confidence interval.

Table 4 (continued)

Variable	Level	No. farms	Crude mortality	Slope parameter	Risk ratio (95% CI)	*P*-value
Northern Cape:	No	55	0.038	−0.234	0.792 (0.483–1.297)	0.354
	Yes	25	0.048	Referent	-	
Eastern Cape:	No	58	0.038	−0.290	0.748 (0.448–1.247)	0.266
	Yes	22	0.05	Referent	-	
Arid/semi-arid:	No	27	0.044	0.110	1.116 (0.688–1.812)	0.656
	Yes	53	0.039	Referent	-	
Grassland:	No	29	0.045	0.134	1.143 (0.710–1.841)	0.582
	Yes	51	0.039	Referent	-	
Lambing season occurred in summer:	No	71	0.044	1.060	2.89 (1.32–6.29)	0.008
	Yes	9	0.015	Referent	-	-
Lambing season occurred in winter:	No	63	0.045	0.602	1.83 (1.03–3.23)	0.038
	Yes	17	0.025	Referent	-	-
Animals routinely vaccinated against pneumonic pasteurellosis:	No	29	0.059	0.631	1.88 (1.17–3.02)	0.009
	Yes	51	0.031	Referent	-	-
Animals routinely vaccinated against chlamydiosis:	No	66	0.044	0.465	1.59 (0.87–2.91)	0.132
	Yes	14	0.028	Referent	-	-
Ewe deworming frequency against wireworm:	<4× per year	44	0.049	0.428	1.53 (0.97–2.43)	0.068
	>4× per year	36	0.032	Referent	-	-
Ewes dewormed with macrocyclic lactones:	No	46	0.047	0.327	1.39 (0.87–2.22)	0.172
	Yes	33	0.034	Referent	-	-
Lambs dewormed with macrocyclic lactones:	No	37	0.049	0.364	1.44 (0.91–2.29)	0.123
	Yes	42	0.034	Referent	-	-

No.: number, CI: confidence interval.

Table 4 (continued)

Variable	Level	No. farms	Crude mortality	Slope parameter	Risk ratio (95% CI)	*P*-value
Singletons in flock:	<75%	38	0.032	−0.433	0.65 (0.41–1.04)	0.071
	>75%	39	0.05	Referent	-	-
Twins in flock:	<30%	50	0.049	0.631	1.88 (1.14–3.10)	0.014
	>30%	27	0.026	Referent	-	-

No.: number, CI: confidence interval.

Table 5 Multivariable analysis of factors associated with feedlot lamb mortality, as found among commercial lamb producers (n = 80) across the major lamb-producing provinces of South Africa in 2024

Variable	Level	No. farms	Slope parameter	Risk ratio (95% CI)	*P*-value
Creep feed (any):	No	32	0.876	2.40 (1.41–4.09)	0.001
	Yes	44	Referent	-	-
Extensive rearing system on farm:	No	19	0.659	1.93 (1.03–3.64)	0.042
	Yes	57	Referent	-	-

No.: number, CI: confidence interval.

Discussion

As with lamb feedlots in other parts of the world, lambs also fail to adapt to the feedlot environment under South African conditions. Anecdotal reports (based on personal practical experience, discussions with multiple experienced production animal veterinarians currently practising in South Africa, and discussions with feedlot managers and owners) suggest that the prevalence of these non-adapting lambs has increased. Veterinarians specialising in feedlot health and production further report that currently available management procedures aimed at ensuring the survival of non-adapter lambs in feedlots appear to be ineffective.

In the present study, the omission of creep feed supplementation increased the risk of lambs becoming non-adapters in intensive feedlot environments by 3.33 times (P <0.001). This substantial effect size indicates that pre-weaning nutrition is a critical determinant of lamb feedlot adaptability under South African conditions. The possible effect of the absence of creep feed supplementation on the likelihood of lambs becoming non-adapters in feedlot systems may be linked to the effect of solid feed intake on rumen development during the pre-weaning phase. The initiation of voluntary intake of dry matter rich in readily fermentable carbohydrates in the post-natal period (commonly referred to as creep feeding), leads to the rumen undergoing substantial changes, including the growth of the smooth muscle layer, epithelial growth, the formation of visible papillae, and the establishment of diverse microbial communities (Sun *et al.*, 2021). Lambs in the present study that did not receive creep feed in the pre-weaning phase would therefore have consumed lower amounts of readily fermentable carbohydrates, which could have limited their rumen epithelial development prior to the transition to high-concentrate feedlot diets.

The physical form and particle size distribution of feed are known to exert an important influence on the anatomical and microbial development of the rumen (Beharka *et al.*, 1998; Pazoki *et al.*, 2017). For example, calves fed a ground diet had shorter papillae with a smaller surface area than calves fed an unground diet, and this coincided with a shift in the rumen microbial population from predominantly cellulolytic to predominantly amylolytic species (Beharka *et al.*, 1998). These findings suggest that solid feed intake in the form of creep feed promotes rumen development by stimulating epithelial growth, regardless of the physical form of the diet.

At birth, the rumen is devoid of any bacteria, protozoa, and fungal species because of the sterile nature of the uterus (Maynard *et al.*, 2012). Following the establishment of the microbial population, rumen fermentation as a result of the bacterial, fungal, and protozoal metabolism of feedstuffs increases in conjunction with increased dry matter intake by the neonate and leads to the production of three main volatile fatty acids (VFAs): acetate, propionate, and butyrate (Judd & Kohn, 2018). Once the VFAs have been absorbed, acetate and butyrate are oxidised into ketones, which play key roles in energy transport (Zhuang *et al.*, 2024), while propionate serves as a major substrate for hepatic gluconeogenesis (Dijkstra, 1994).

Of the VFAs produced, butyrate is particularly crucial for stimulating rumen papillary development, followed by propionate and then acetate (Tamate *et al.*,1962; Baldwin *et al.*, 2004). Butyrate positively influences short-chain fatty acid absorption (Malhi *et al.*, 2013; Dengler *et al.*, 2015), rumen papillary blood flow (Storm *et al.*, 2011), and rumen motility (Kendall & McLeay, 1996). The intraruminal infusion of sodium butyrate increases papillae length, width, and surface area, as well as the thickness of the stratum corneum (Liu *et al.*, 2019). In addition, butyrate regulates rumen epithelial cell proliferation and survival by modulating gene networks and the expression of genes that promote cell division (Connor *et al.*, 2013; Malhi *et al.*, 2013; Lin *et al.*, 2022), while inhibiting apoptosis (Liu *et al.*, 2019). Given the significant risks associated with creep feed omission in the pre-weaning phase, insufficient rumen epithelial development as a result of a lack of chemical stimulation by butyrate may lead to limited rumen function at the point of feedlot entry, thereby limiting the capacity of these lambs to adapt and perform under intensive feedlot conditions.

Lambs raised under extensive rearing systems were 2.57 times more likely to not adapt to intensive feedlot conditions (P = 0.003). In extensive systems in South Africa, the creep feeding of lambs or supplemental feeding of ewes is often provided inconsistently and only at convenient, accessible locations, such as near camp gates. Consistent intake of creep feed is essential to stimulate rumen microbial activity and increase the production of VFAs, especially butyrate, which plays a key role in promoting rumen papillae growth and enhancing the absorptive surface area of the papillae (Liu *et al.*, 2019). The sporadic supply of creep feed under extensive conditions fails to maintain a continuous intake of readily fermentable carbohydrates, potentially limiting microbial activity and butyrate

production. Furthermore, the absorption rates of VFAs are influenced by rumen papillary surface area (Dirksen *et al.*, 1984; Gäbel *et al.*, 1991a,b), suggesting that as the rumen papillary surface area increases, the rate of VFA absorption could exceed production, particularly when creep feed intake is inconsistent.

In addition, irregular or limited creep feed intake, as observed in this study, might shift fermentation towards milk- or roughage-based substrates. The ratios of acetate, propionate, and butyrate produced in the rumen are influenced by forage type and the species and quantity of rumen bacteria (Alstrup *et al.*, 2016; Bharanidharan *et al.*, 2018). The forage-to-concentrate ratio had no effect on total VFA production but influenced the acetate-to-butyrate ratio (Zhang *et al.*, 2017). Therefore, a higher roughage diet would result in the production of more acetate and less butyrate, potentially slowing rumen papillary development and limiting rumen function. Lambs reared extensively with minimal supplementation may therefore experience a rumen fermentation profile that is not conducive to promoting rumen papillary development prior to weaning, contributing to the inability of extensively raised lambs to adapt and perform in South African feedlots. Along with the physiological implications associated with the omission or inconsistent provision of creep feed, animal welfare might also be impacted, as nutrient levels on cultivated pastures might not meet the nutritional needs of lambs during critical developmental stages, and may thus lead to poor growth rates (Brand *et al.*, 1999). Therefore, creep feeding is particularly beneficial when low pasture quality or quantity limits ewe milk production or when ewes are in poor body condition prior to lambing, both of which can hinder lamb performance (Alcock, 2006).

Lambs raised outside of the summer season were also 2.59 times more likely to not adapt to feedlot systems (P = 0.039). Seasonal variation in pasture quality and availability can affect ewe nutrition, milk production, and subsequent lamb growth prior to weaning (Inyangala *et al.*, 1992). During the colder months, when pasture productivity is naturally lower and ewe milk production is reduced, lambs may not receive adequate nutrition from either the pasture or suckling from the dam, potentially compromising early growth. During the pre-weaning phase of a ruminant's life, the rumen is colonised by bacteria, archaea, fungi, and protozoa, which play important roles in diet fermentation and thus the host's energy supply (Lin *et al.*, 2019). Rumen microbial inoculation and colonisation are crucial in aiding the transition of the animal from a functional monogastric to a ruminant. As a result of reduced nutrient digestion and absorption in lambs during months outside of summer, a catabolic, cachectic, and hypothermic state could be induced, negatively affecting rumen development by hindering rumen microbial colonisation and subsequent fermentation, and ultimately influencing feedlot adaptability post-weaning (Furman *et al.*, 2020; Guo *et al.*, 2020).

In addition to creep feed supplementation, extensive lamb rearing, and lambs raised outside the summer season, other variables that were significant in the univariate analyses included lambing season, the proportion of twins in the flock, and routine vaccination against pneumonic pasteurellosis, despite these factors not being retained in the multivariable model. This indicates that multiple nutritional, management, and health-related factors can influence lamb adaptation and survival in an intensive feedlot environment.

Geographically, non-adapting lambs were distributed across four provinces in South Africa, with the Free State, Northern Cape, Eastern Cape, and Western Cape having a higher prevalence of non-adapting lambs (Figure 1). Additional univariate analyses for regional factors (semi-arid/arid versus grassland biomes) were performed but were not significant, indicating that the observed clustering cannot be explained by broad ecological regions. The significant clustering of non-adapting lambs (Z: 2.62, P = 0.009) therefore suggests that provincial-level factors, rather than regional factors alone, might contribute to the development of high-risk lambs. Importantly, the Cuzick–Edwards test used to assess clustering accounts for the baseline distribution of farms in the study area and is not influenced by provincial boundaries. One possible explanation is the higher density of lamb producers in these provinces, which are traditionally South Africa's largest lamb-producing areas and are all located in semi-arid regions. These areas can only support low numbers of livestock units per hectare, resulting in more extensive farming systems where animals rely on natural veld, as opposed to a continuous supplemental feeding strategy. These large areas and low stocking densities make consistent management and close monitoring difficult, limiting the early identification of poorly performing lambs.

Extensive farming systems are popular among South African farmers and are commonly used for several reasons, including their lower capital input requirements compared to intensive operations, which require high cash inputs (Karthik *et al.*, 2021). Despite the popularity of extensive systems, they

pose challenges for livestock production, including poor seasonal pasture quality that compromises animal nutrition (Goddard *et al.*, 2006; Dwyer, 2009; Villalba *et al.*, 2016), and increased neonatal mortalities resulting from inadequate ewe-lamb bonding (Dwyer, 2008), leading to the starvation-mismothering-exposure complex (Celi & Bush, 2010). Despite the common perception that extensive systems promote animal welfare, they can also pose welfare risks, including nutritional deficiencies, loss of body condition, chronic hunger, and increased susceptibility to internal parasites (Temple & Manteca, 2020). The present study suggests that lamb rearing systems require a gradual shift towards more semi-intensive or intensive management, with closer monitoring of pre-weaned lambs and consistent, timely creep feed supplementation prior to weaning. These practices would have long-term benefits for rumen development, improve lamb performance, and minimise the risk of non-adapter lambs entering South African feedlots. That being said, in the South African context, lamb producers are strongly profit-orientated and focus on minimising input costs to maximise their profit margins. Providing creep feed to lambs prior to weaning is one of the largest expenses for farmers who sell weaner lambs to feedlots.

The benefits associated with creep feed supplementation are well known, as seen in the studies performed by Hayes *et al.* (2019) and Ramli *et al.* (2025), where supplying creep feed during the pre-weaning stage significantly improved the weaning weights and average daily gains of Dorper lambs and goat kids. However, the market price for weaner lambs, which is typically determined by the feedlot, is rarely influenced by on-farm managerial practices such as creep feed supplementation, despite this practice resulting in younger, heavier weaner lambs. As a result, producers may view creep feeding as an unnecessary expense owing to the lack of financial incentives.

While this study provides valuable insights, the findings should be interpreted in light of several potential limitations. Lamb batches were raised on selected farms for approximately four months before being sold to feedlots, where they were fed for 60 days. The three-week interval between abattoir data collection and questionnaire administration may have introduced recall bias, and complete management records were not always available. Other limitations include the relatively small sample size and the inability to adjust for unmeasured confounding variables. For example, individual ewe- and lamb-specific data, such as ewe age, ewe nutritional status, ewe body condition score at lambing, lamb birthweight, and lamb health status during the pre-weaning period, are all important factors that could not be accounted for in this study. Variables such as age at weaning and lamb-ewe contact on pasture were not included in the questionnaire and may represent additional risk factors that could be considered in future studies. In addition, variations between feedlots, including the feed used, the transport distances, and the different management systems at each feedlot site were not controlled for in this study. Furthermore, despite the bilingual proficiency of the principal author in English and Afrikaans, if one of these languages was not a farmer's first language, this could have introduced information bias owing to the potential misunderstanding of questions during questionnaire administration.

Conclusion

This study identified key risk factors associated with non-adapting lambs, providing valuable insights into farming practices that predispose these high-risk animals to poor performance upon feedlot entry in South Africa. Lambs that have not been provided with creep feeding, that have been raised under extensive systems, and that have been raised outside of the summer months should be regarded as high risk and managed accordingly at the feedlot. A major contributing factor appears to be the lack of communication between weaner lamb producers and feedlot buyers. Both parties operate under strongly profit-driven motives, and in the absence of a standardised pricing system that rewards producers for implementing good agricultural practices such as proper nutrition and timely vaccinations, there is little incentive to improve pre-feedlot management. Until such a system is adopted, cost-cutting practices are likely to persist, perpetuating the cycle of poor adaptation and associated livestock losses.

Acknowledgements

The authors thank all the farmers for their participation in the data collection during questionnaire administration.

Author contributions

J.D.M. was involved in investigation, formal analysis, writing (original draft preparation), visualisation, and data curation. G.F. designed the study, analysed the data, and revised the manuscript. S.J.C. was involved in the

supervision of the study and reviewing the manuscript. L.O. and E.C.W. were involved in the revision of the manuscript.

Conflict of interest declaration

The authors declare no financial, personal, or other relationships with individuals or organisations that could inappropriately influence this work. This study did not recieve any external funding.

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