Effects of grain-free calf starter on crossbred dairy-beef calf feed intake, growth, weaning age and post-weaning performance

Final Report

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RESEARCH SUMMARY

Inseminating dairy cows with the semen of beef breed bulls can improve the quality of beef of dairy origin while also providing access to 'value-add' markets such as the Greenham dairy beef program. This program requires that cattle are 100% grass-fed, that is, that they are never fed cereal grains or their by-products. This experiment examined the growth of dairy-beef crossbred calves reared on a commercially available grain-free calf starter in comparison to a commercially available cereal grain-based starter. Thirty male and 30 female Holstein × Speckle Park calves were studied. Calves were transported to the Tasmanian Institute of Agriculture Dairy Research Facility (TDRF) at 3 days of age where they were weighed and mixed into four bedded pens of 15 animals. Pens were fitted with an automatic calf feeder through which calves were offered 5L of milk replacer per day supplemented with ad libitum starter pellets. Two pens were provided a cereal grain-based calf starter ('control' treatment) while the other two received a commercially available faba bean-based grain-free starter ('grain-free' treatment). Calves remained in treatment groups after weaning at 13.5 weeks of age. Post-weaning, calves had ad libitum access to pasture supplemented with 2 kg starter per calf/day. They remained in these groups under this management until the experiment ended at 19 weeks of age. Calves were weighed fortnightly throughout the experiment, and automatic calf feeders recorded the amount of milk (L) and starter (g) consumed by individual calves each day. Intakes of milk replacer (mean ± standard deviation; 4.7 ± 0.4 L/day) and total pellet (40 ± 15 and 45 ± 19 kg for control and grain-free calves, respectively) were comparable between treatments. Feeding cost until weaning for control calves was \$367.50/calf and for the grain-free calves was \$374.80/calf. There was no difference between control and grain-free treatments for pre-weaning growth (0.52 ± 0.12 and 0.58 ± 0.14 kg/day, respectively), weaning weights (83 ± 12 and 88 ± 14 kg, respectively), days to reach 100 kg (107 ± 13 and 102 ± 15, respectively), or post-weaning growth (0.80 ± 0.12 and 0.74 ± 0.17 kg/day, respectively). Nearly 32% of calves became unwell during this trial and required treatment with antibiotics and/or anti-inflammatory medication. Compared to calves never medically treated or were treated once, calves that were treated multiple times gained less weight pre-weaning (0.59 ± 0.12, 0.52 ± 0.1 and 0.37 ± 0.07, respectively), were lighter at weaning (89 ± 13, 85 ± 10 and 71 ± 6 kg, respectively), took longer to reach 100 kg (101 ± 14, 105 ± 11, 125 ± 3 days, respectively), and remained lighter post-weaning (105 ± 14, 104 ± 11 and 89 ± 7 kg at 16 weeks of age, respectively). The cereal grain-based and faba bean-based grain-free starter pellets used in this experiment delivered comparable levels of energy and protein, which likely resulted in a similar rumen development and calf growth. In this experiment, poor health was more likely to extend the time to weaning and increase rearing costs than a grain-free requirement.

INTRODUCTION

Opportunities to realise the potential value of surplus calves lie in improved rearing systems and market pull-through for dairy beef (Bolton and Von Keyserlingk 2021). Developing a market for surplus calves to be reared for the beef production chain in Australia presents a potential alternative source of income for dairy farmers while also addressing persistent welfare concerns. Adding economic value to the surplus calves may make their rearing for the beef market a financially viable alternative to early slaughter for farm business owners.

Meat processing company Greenham Australia is piloting a new dairy beef supply chain in Tasmania. This program aims to produce dairy origin beef cattle that meet stringent quality requirements and address key consumer purchase drivers. Requirements include not feeding grain or grain by-products and no prophylactic antibiotics.

Traditional dairy calf rearing systems rely on the early intake of grain-based calf starter to promote sufficient rumen development and facilitate early weaning, thereby minimising rearing costs. It is hypothesised that rearing calves on a grain-free starter will delay rumen development, thereby increasing time to weaning and compromising post-weaning performance in comparison to grain-based starters. This in turn could increase the cost of rearing. The existing body of literature on grain-free calf starter use is limited. Recent New Zealand research shows that Wagyu × Friesian calves reared on an ensiled alfalfa starter have slower growth pre-weaning than those reared on a cereal-based pelleted starter, however, they experience accelerated growth post-weaning (Burggraaf *et al.* 2020a; Khan *et al.* 2020). Neither study found long-term effects on starter diet on liveweight or carcass quality, suggesting that forage fed calves may be better prepared for weaning onto pasture. While these studies provide valuable preliminary insights, research is required to understand the Australian context, including using a locally sourced grain-free starter formulation, Australian rearing conditions, and dairy-beef crossbred genetics common to the Australian industry.

Tasmanian dairy producers have identified the requirement to rear calves on a grain-free starter as a potential barrier to adoption of a grass-fed dairy beef supply chain. Quantifying the impact of grain-free starter provision on calf performance and weaning will allow for a better understanding of the rearing costs associated with grass-fed dairy beef supply chains. This will equip producers with the information to make a more informed assessment of the economic feasibility of these supply chains to their business.

This project assessed the growth and health of dairy-beef crossbred calves reared on a grain-free calf starter in comparison to a traditional grain-based starter. Data on milk and pellet intakes, calf weights and growth pre- and post-weaning and health were be collected.

MATERIALS AND METHODS

Ethical statement

All animal procedures were conducted with prior institutional animal ethics approval (University of Tasmania Animal Ethics Committee A0026833) under the requirement of the Tasmanian Animal Welfare Act (1993) in accordance with the National Health and Medical Research Council/Commonwealth Scientific and Industrial Research Organisation/Australian Animal Commission Australian Code of Practice for the Care and Use of Animals for Scientific Purposes.

Animals and experimental design

This experiment was conducted over 19 weeks from February to June at the Tasmanian Institute of Agriculture Dairy Research Facility (**TDRF**), Elliott, in north-west Tasmania, Australia. Thirty male and 30 female dairy-beef crossbred calves (Holstein × Speckle Park) were studied from 3 days of age until 19 weeks of age. A sample size of 30 calves per treatment was determined as sufficient to detect a ≥10% difference in weaning weight and ≥21% difference in pre-weaning average daily gain (**ADG**) with 80% power at $P \geq 0.05$. Previous literature suggests up to 20% difference in weaning weight and up to 28% difference in ADG could be expected (Burggraaf *et al.* 2020a; Khan *et al.* 2020).

Calves were housed in four pens of 15 animals and offered either a standard grain-based commercial calf starter (‘control’ treatment - TasStockFeed, Calf Pellet 21; n=2 pens) or a commercially available grain-free calf starter (‘grain-free’ treatment - TasStockFeed, Grain-free calf 20; n=2 pens) in addition to 5L of milk replacer per day (Profelac silver). Further details on calf management are provided in the following paragraphs.

Early life management. Calves were born on a large commercial dairy farm, separated from their dam at birth, had their naval sprayed with iodine and housed indoors in bedded pens. They were provided with 2L of high-quality colostrum within 6 h of birth (IgG concentration >50 mg/mL measured via Brix refractometer) and at least another 2L from 12-24 h of birth. A blood sample was obtained from twelve randomly selected calves that had no signs of disease or dehydration at 2-days old via jugular venepuncture. Samples were used to assess total protein levels as an estimate of successful passive transfer of immunity in the cohort. The rate of failure of passive transfer was 16.7% and rate of adequate passive transfer of immunity was 75% (Appendix 1).

Calves were fitted with a NLIS RFID tag and transported as a single cohort from the source farm to the TDRF at 3-days of age (approximately 1.5 h journey). They were fed the morning and loaded for transportation at approximately 12 noon. Calves were transported with bedding on the bottom level of the fit for purpose truck which provided protection from wind and rain. The truck was operated by a trained and experienced livestock driver.

Pre-weaning housing and management. Calves were unloaded upon arrival at TDRF, weighed, given an additional naval disinfection and an identification ear tag, and allocated to one of 4 bedded pens (n=15 animals/pen) balancing for sex, average weight and variation in weight (Table 1). The calf shed was partially enclosed which provided natural ventilation and lighting. Pen floors were made of compacted soil topped with 1 foot of woodchip bedding. Pens contained a solid bristle calf brush attached to the wall of the pen and one large inflatable ball suspended from the roof.

Table 1. Start weights, variability in start weights, and sex over pens

	Pen 1	Pen 2	Pen 3	Pen 4
Starter treatment	Grain-free	Control	Grain-free	Control
Number of calves	15	15	15	15
Male:Female ratio	8:7	8:7	7:8	7:8
Average weight ± standard deviation, kg	36.6 ± 4.8	36.8 ± 4.0	36.9 ± 4.0	36.9 ± 4.4
Co-efficient of variation in weight (%)	13	11	11	12
Average weight of females	33.6	34.1	35.6	36.1
Average weight of males	39.2	39.3	38.4	37.7

Each pen was fitted with an automatic calf feeder fixed to cement flooring and through which calves were offered electrolytes in the afternoon after arrival and 5L of milk replacer from the morning of the following day (Profelac silver). Equipped with an RFID tag reader, the automatic feeders recognise individual calves and record how much of their daily milk and starter allowance has been consumed. Milk replacer was made fresh, feeding lines were flushed, nipples were scrubbed and disinfected, and pens were cleaned each morning of the experiment. The autofeeders also dispensed calf starter ad libitum. Two pens were provided the control calf starter (i.e., grain-based) and the other two the grain-free starter ('grain-free', faba bean-based starter). Formulations were comparable in protein and energy (Table 2). Water was provided ad libitum via a drinking nipple.

Calves were continuously monitored from 0800-1700 h with an additional evening check at 2100 h for the first 3-weeks after their arrival to TDRF. This time was used to train calves to the autofeeder, to assist those that were failing to feed, and to monitor health. After the first 3-weeks monitoring was reduced to 0800-1100 h with an addition afternoon (1500 h) and evening (2100 h) health and feeding check. Training calves to the auto-feeder involves gently leading them into the feeder, releasing some milk onto the nipple and allowing them to suck. Calves have a strong suckling instinct, and most were trained within a few feedings. Three calves failed to effectively use the feeder and were bottle fed throughout the experiment; one from the grain-free (pen 1 - female) and two from the control treatment (pen 2 - male, pen 4 - female).

Table 2. Mean nutritional composition of the pelleted grain-based starter (Control) and faba bean-based grain-free starter ("Grain-free") offered to dairy × beef calves. Both starter types were produced by TasStockFeeds and are commercially available.

Component	Control	Grain-free
DM%	91.4	92.1
Crude protein (% of DM)	21.3	20.8
Starch (% of DM)	33.6	23.4
Sugar (% of DM)	4.0	11.0
ADF (% of DM)	10.2	14.2
NDF (% of DM)	25.4	27.3
Ash (% of DM)	9.2	10.1
Crude fat (% of DM)	3.3	5.5
ME (MJ/kg DM)	12.5	12.5

ADF, acid detergent fibre; ME, metabolisable energy; NDF, neutral detergent fibre

Post-weaning housing and management. Calves were weaned onto pasture at 13.5 weeks of age following a gradual reduction in milk allowance over the preceding 4 days. Two paddocks were used to house the calves according to treatment; i.e., the two pens of calves fed the grain-free diet were mixed and the two pens of calves fed the control diet were mixed. Calves continued to be fed 2 kg of their respective calf starter per day, split over an AM and a PM feeding. Starter was distributed via 4 × 2 m long feeding troughs per group that were accessible on both sides providing a density of 7 calves per trough.

A generous pasture allowance was provided to ensure calves had ad libitum access to forage (see Appendix 2 for details on pasture allocation). The groups were initially housed in adjacent 1.3 hectare paddocks containing ~3,000 kg DM/ha, providing enough pasture for approximately 25 days with an allocation of 1-1.5 kg DM per calf and residual of 2500 kg DM/ha. Each paddock contained a water trough and calf shelter (6.5 × 3 m) with solid walls and roof. Calves could access the entire paddock area for the first 48 h post-weaning, while they became fence-trained and adjusted to the housing conditions. After this they were provided pasture in 3-5 day allocations using 3-strand temporary electric fencing. Calves were shifted to new paddocks, remaining separated by treatment, at 3-weeks post-weaning. The new paddocks were 110 × 110 m (1.2 hectares) and contained ~3,900 kg pasture DM/ha, enough for 33 grazing days with an allocation of 2 kg DM per calf and residual of 2500 kg DM/ha. They remained in these paddocks for the final 2.5 weeks of the experiment after which they were transported to a commercial farm for backgrounding and finishing.

Measures recorded

Milk, starter, and pasture consumption. The automatic calf feeders recorded the amount of milk (L) and starter (g) consumed by individual calves each day. These data allowed for calculation of the percentage of milk offered that was consumed per day, and the total amount of milk and starter consumed over the pre-weaning period.

Pasture intakes during the post-weaning period were based on herbage mass estimates using a rising plate meter (Farmworks Systems, Feilding, New Zealand) with the following site-specific calibrated equation:

$$y = 240\,x + 500$$

where y = estimated pasture biomass in kg DM/ha, and x = number of centimetres in compressed pasture height. Estimated pasture intakes (kg DM/calf) were then calculated as the difference between the pre- and post-grazing herbage mass and averaged per calf in the group.

Live weight and growth. Calves were weighed upon entry to TDRF and fortnightly thereafter. From these data the following were determined: days to double start weight, weight at weaning, pre-weaning ADG, weight 3-weeks post-weaning, post-weaning ADG, overall ADG (from arrival at TDRF to 3-weeks post-weaning).

Health. The health of individual calves was recorded daily for the first 3-weeks following calves arrival to TDRF and weekly thereafter. Calves were provided a score from 1-3 during health inspection (generally interpreted as 1 = no issue, 2 = slight-moderate issue, 3 = moderate to serious issue; Appendix 3) for the following categories: vigour, nose/eye discharge, cough, scouring, navel, feeding and bloat. The following details were recorded for all instances when medical treatment was required (typically with the non-steroidal anti-imflammatory Flunixin (**NSAID**) and/or the anti-biotic Trisoprim): date, calf identification, calf temperature, ailment, type of treatment and days of treatment.

Statistical analysis

All statistical analyses were carried out using the SPSS statistical software package (SPSS 28.0, SPSS Inc.). Health data were largely subject to a descriptive analysis. All other variables were assessed for normality using visual methods (quantile-quantile plots and histograms) in combination with Shapiro-Wilks normality tests. Total milk consumed underwent a $y = \log_{10}(k - total\ milk\ consumed)$ transformation, where k = the largest possible value + 1, before analysis so that residual variation was homogenous between starter treatments. The significant level α was set at P ≤ 0.05 and trends were described at P ≤ 0.10. To aid with interpretation, raw data are presented in this report with estimated marginal means (**EMM**) [or transformed EMM (and backtransformed EMM)] ± SEM presented in Appendix 4.

Live weights at week 18 (5-weeks post-weaning) were excluded due to an extreme weather event which compromised scale function. The animals in this trial experienced several health challenges, the details of which are described in the results of this report. Eighteen calves (30%) were put on a course of medical treatment. Eleven received one course of medical treatment. The other 7 calves received multiple courses of medical treatment (average 3.1 courses, range 2-4). A new variable called “Medical treatment” with three levels (placed on medical treatment zero, once or multiple times) was created for analysis. A univariate ANOVA with start weight as the dependent variable and medical treatment as the fixed factor was used to determine if smaller calves were more likely to become sick in this experiment. A Chi-square test for independence was used to determine whether (1) males and females and (2) calf starter treatments were equally represented in each classification of medical treatment.

Total milk and starter consumed during the pre-weaning period, and all weight variables (excluding days to double weight) were analysed using linear mixed models. Each model included the fixed effects of starter treatment (grain vs. grain-free), calf sex and medical treatment (zero, once, multiple) as well as their 2- and 3-way interactions while pen was controlled for as a random blocking factor. Relationships between start weight and data relating to intake and weights were assessed using Pearson (for normal data) or Spearman (for non-normal data) correlations and scatterplots (Figure 1). The positive relationship between start weight and total milk consumed was largely affected by four calves with low consumptions from the control treatment (Figure 1A). This correlation was not significant when these animals were removed and so was not included in the final model for total milk consumed. Start weight was retained as a covariate for the analyses of weaning weight, days to 100 kg weight and final weight at week 16. The number of days for calves to double their weight could not be normalised. The effects of starter treatment and sex on this variable were assessed with a non-parametric Mann-Whitney U-test while the effects of medical treatment were assessed with a Kruskal-Wallis non-parametric test.

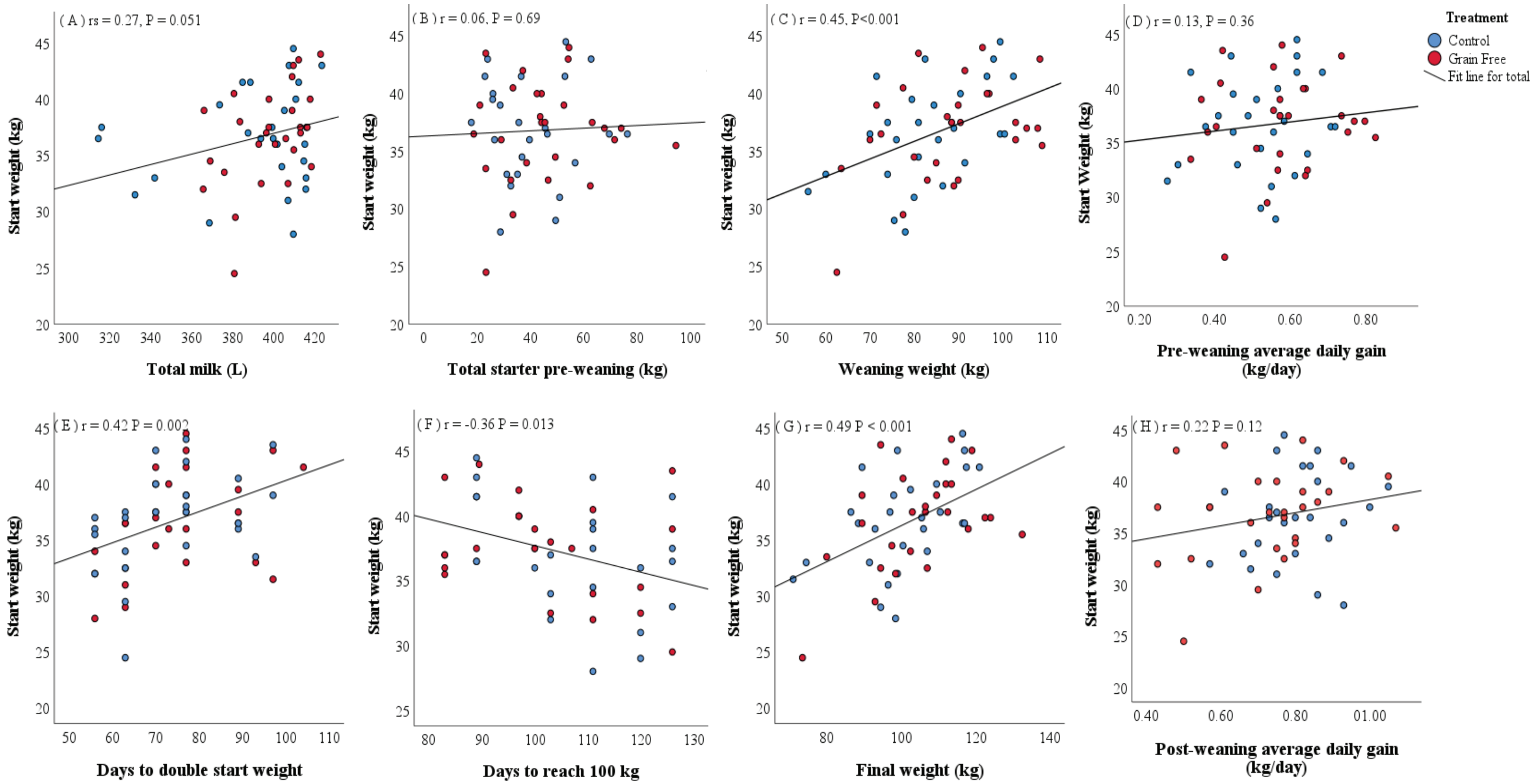

Figure 1. Relationships between calf weight at arrival to TDRF (y-axis) and the (A) total milk and (B) total starter they consumed during the pre-weaning period, their (C) weaning weight, (D) pre-weaning average daily gain, (E) days to double their start weight, (F) days to reach 100 kg, (G) weight at week 16 and (H) post-weaning average daily gain. Data points are separated by treatment and trend lines are also provided.

RESULTS

Health

Cryptosporidium outbreak. Calves started scouring within 24-48h of arrival to TDRF. Over 60% of all calves were scouring at day 3. The proportion of calves within pens scouring peaked at 80-90% (Figure 2A). Scouring was observed in all pens and was accompanied by varying degrees of blood in the faeces, low vigour, and inappetence. A calf treatment plan was developed with the TDRF veterinarian to ensure fast and consistent treatment of sick animals. Any calf that was scouring with blood but was otherwise unaffected (i.e., high vigour, good appetite, normal temperature) remained in its pen but commenced 3-day course of antibiotics. Scouring calves with any combination of inappetence, low vigour and high temperature were moved to the sick pen and commenced treatment of fluids, antibiotics and NSAID. The number of treatments provided and reasons for treatment is described in Table 3.

There were two mortalities in the first week of the trial (Appendix 5). A necropsy found pneumonia to be the cause of a sudden death on day 3. The second calf that died had been receiving intensive care in the sick bay under veterinary advice. He had confirmed cryptosporidium infection and succumbed to illness. Other faecal samples taken from the pens during this time also tested positive to cryptosporidium.

Coccidia infection. A second scouring event was evident from week 4 (Figure 2A). Faecal samples tested positive to coccidia and upon veterinary advice all animals received Baycox and commenced an “in-pen” fluids treatment using Neolyte (i.e., a calf electrolyte solution with no milk withholding period). Two calves died during the coccidia outbreak, both were receiving intensive care in the sick pen under veterinary advice (Appendix 5). Scouring declined within 2-weeks of Baycox treatment and remained low for the remainder of the trial (Figure 2B). There were no further mortalities in the pre-weaning period.

Respiratory infection. Coughing was recorded from approximately week 8, peaking at week 9 (Figure 2B). As with the scouring, respiratory infection was distributed across all pens (Figure 2C). Ten calves were treated under veterinary guidance due to coughing with a high temperature (4 grain-free and 6 control treatment calves). Five of these were treated more than once (range 2-4 times). There was a calf mortality at 7 days post-weaning. A necropsy concluded that subacute bronchopneumonia was the cause of death. Full details of all mortalities are presented in Appendix 5.

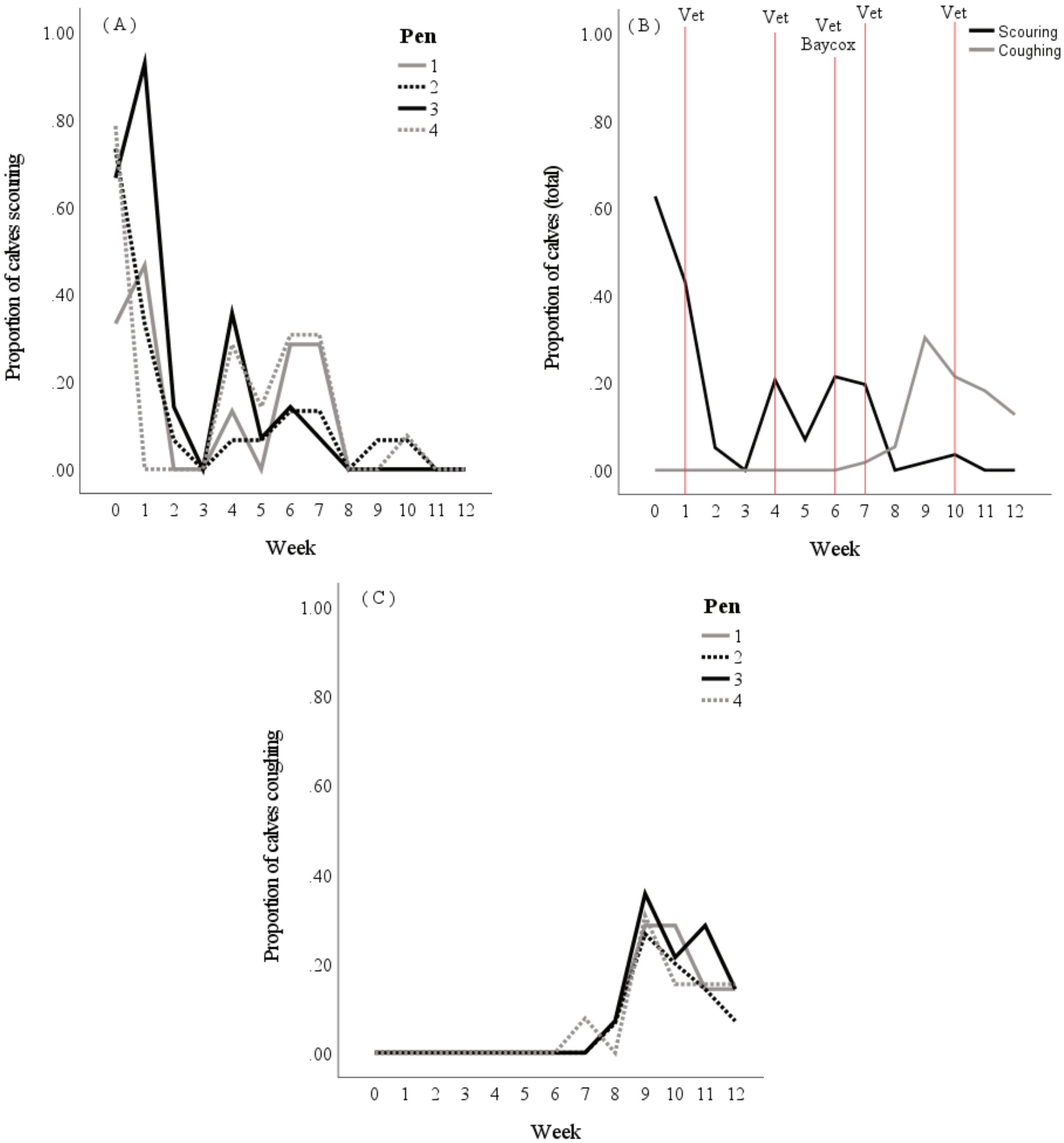

Figure 2. The proportion of calves (A) scouring per pen, (B) scouring and coughing in total and (C) coughing per pen, over weeks of the pre-weaning period. Reported data correspond to a point-in-time weekly health assessment. The red vertical lines in (B) indicate health assessment of calves by the TDRF veterinarian, and treatment of all calves with Baycox.

Table 3. Details of medical treatments. The treatment administered, the reason for that treatment, and the number of calves that received that treatment for that reason are described. Note that treatments are not mutually exclusive (i.e., more than one treatment could be administered at the same time).

Treatment[1]	Reason	Number
Trisoprim	Scouring with blood, may also have low vigour and/or reduced appetite and/or high temperature	13
Flunixin	Scouring (no blood), may also have low vigour and/or reduced appetite and/or high temperature	15
Flunixin	Coughing with high temperature and/or low vigour	15
Flunixin	High and/or low temperature with reduced appetite	2
LA Alamycin	Pneumonia	2
LA Alamycin	Abscess	1

[1]Trisoprim = antibiotic for systemic treatment of bacterial infection. Flunixin = non-steroidal, anti-inflammatory, analgesic, antipyretic with anti-prostaglandin effects. LA (long acting) Alamycin = a long-acting broad spectrum antibiotic, blood levels persist for at least 4 days.

Medical treatment classifications. Thirty-eight calves received no medical treatments (67.9%), 11 received one course of medical treatment (19.6%) and 7 were treated more than once (12.5%). There was no relationship between medical treatment classification and calf weight at entry to TDRF ($F_{2,19.5}$=1.1, P=0.36). Medical treatment classifications were evenly distributed over the control and grain-free starter treatments (χ^2=0.94, DF=2, P=0.63), however, males tended to be treated more frequently than females (χ^2=5.9, DF=2, P=0.051; Table 4).

Table 4. The number of male/female and control/grain-free calves that received none, one or multiple periods of medical treatment.

	Medical treatment classification		
	None	Once	Multiple
Male	15	8	6
Female	23	5	1
Grain-based starter (‘control’)	20	5	4
Grain-free starter (‘grain-free’)	18	8	3

Milk and starter consumption

Calves took around 2 weeks to become fully trained to the feeder (Figure 3A). Reduced consumption at week 13 is due to the gradual weaning program. From weeks 3 to 12 calves consumed an average of 4.7 ± 0.4 L of milk replacer/day, corresponding to 91% of their daily milk allocation.

Interactive terms were not significant in the analysis of milk and starter consumption. Raw means ± standard deviations for variables related to pre-weaning intakes are presented in Table 5.

The total amount of milk replacer consumed was not affected by the type of calf pellet provided ($F_{1,3}$=0.10 P=0.78). There was a tendency for males to consume more milk than females, but the actual difference between the sexes was marginal ($F_{1,42}$=3.1 P=0.087). Calves that received more than one medical treatment consumed less milk than those treated once or zero times ($F_{2,41}$=6.6 P=0.003 Figure 3A).

Starter treatment did not affect the amount of pellet consumed pre-weaning ($F_{1,3}$=0.02 P=0.91 Figure 3B) and consumption was comparable between males and females ($F_{1,42}$=0.43 P=0.52). One female from the grain-free treatment consumed a total of 94.6 kg of starter, which was more than double the average of 41.6 kg and increased both the mean and variability of starter intake by females. Calves that received no medical treatments tended to consume more starter than those that did ($F_{2,41}$=2.6 P=0.089 Figure 3C).

Estimated pasture consumption post-weaning

Estimated pasture consumption over 38 days post-weaning was comparable between treatments ($F_{1,10}$=1.3 P = 0.28). Heifers fed the control pellet consumed an estimated 2.0 ± 0.83 kg pasture DM/day and heifers fed the grain-free pellet consumed an estimated 1.5 ± 0.45 kg pasture DM/day.

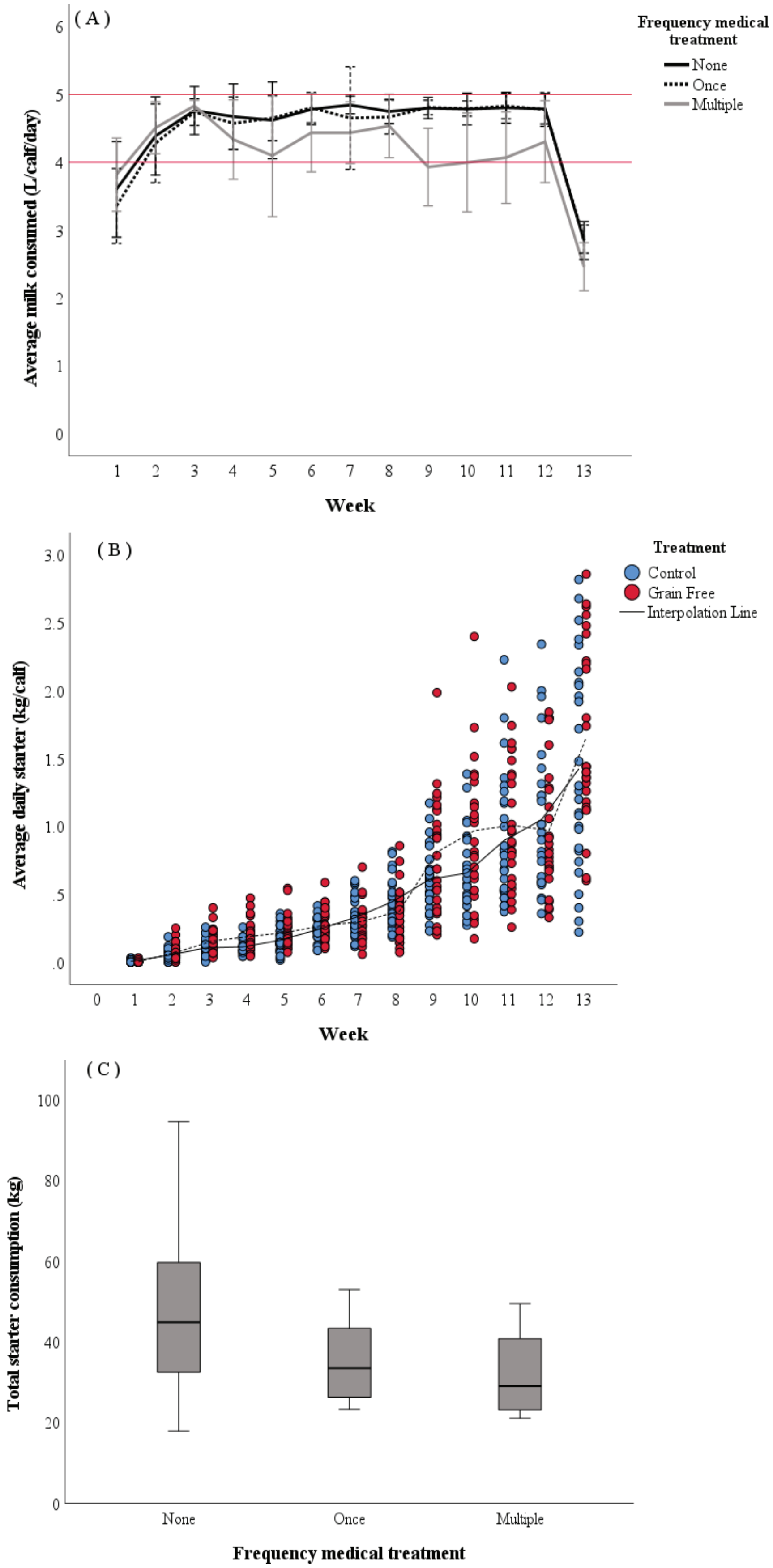

Figure 3. Effects of starter treatment or the frequency of medical treatment on variables relating to intake during the pre-weaning period.

Growth

There were no significant 2- or 3-way interactive effects, and generally no sex effects (unless mentioned), on variables relating to pre- or post-weaning growth. Raw means ± standard deviations for the main effects of starter treatment, sex and frequency of medical treatment are presented in Table 5.

Pre-weaning growth

Starter treatment did not affect the number of days to double start weight (U=314, N=54, P=0.38), the weaning weight ($F_{1,42}$=0.24 P=0.63 Figure 4A) or the ADG until weaning ($F_{1,43}$=0.30 P=0.59). Pre-weaning growth was affected by whether a calf received medical treatment. Calves that received multiple treatments had a lower daily weight gain ($F_{2,43}$=8.3 P<0.001) and so took longer to double their weight (χ^2_2=12.8, N=54, P=0.002) and were lighter at weaning ($F_{2,42}$=8.6 P<0.001 Figure 4B) than calves that had zero or one medical treatment. Calves that received no medical treatments were also heavier at weaning than those that were treated once.

Post weaning growth

There were no effects of starter treatment on days to reach 100 kg ($F_{1,38}$=0.32 P=0.57), the final weight at 16-weeks of age ($F_{1,42}$=0.3.5 P=0.56 Figure 4A), post-weaning ADG ($F_{1,42}$=1.7 P=0.20), or the ADG from birth until week 16 ($F_{1,42}$=0.19 P=0.66).

Medical treatment classification did not affect post-weaning ADG ($F_{2,42}$=0.76 P=0.47) but calves that received multiple medical treatments in the pre-weaning period remained lighter than the other calves (days to reach 100 kg $F_{2,38}$=9.7 P<0.001, final weight $F_{2,42}$=6.6 P=0.003; Figure 4B) and had a lower ADG from birth until 16-weeks of age ($F_{2,42}$=6.3 P=0.004).

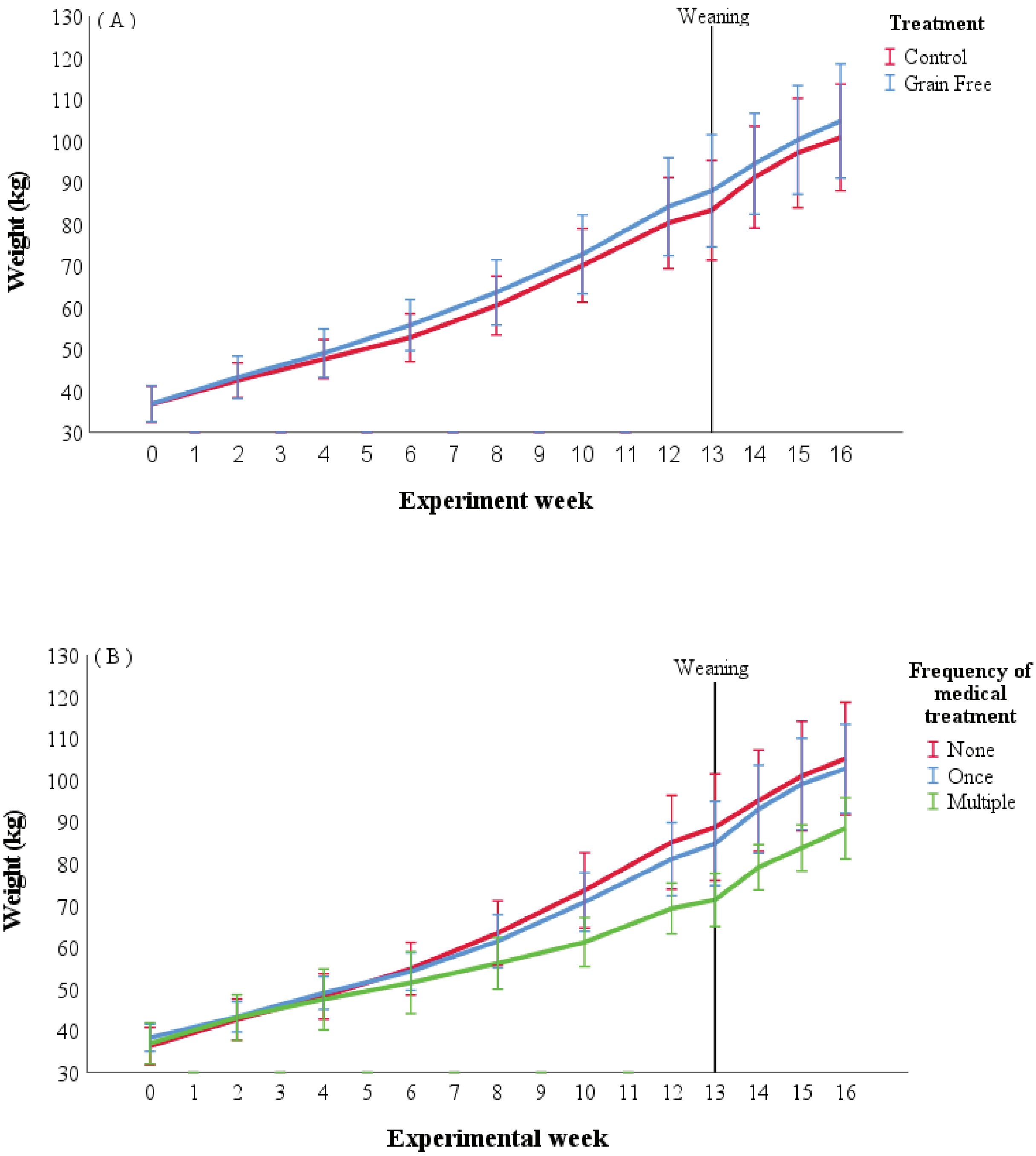

Figure 4. Weight changes over weeks of the experiment by (A) starter treatment and by (B) the frequency of medical treatment.

Table 5. Raw means ± standard deviation for the main factors used in the analysis of variables relating to calf intakes and growth. Median values are also presented when a non-parametric analysis was used.

	Starter treatment		Sex		Frequency medical treatments		
	Control	Grain-Free	Male	Female	None	Once	Multiple
Number of calves analysed	27	27	28	26	36	11	7
Intake variables							
Total milk, L (average milk per day)	391 (4.7) ± 31.0	398 (4.7) ± 17.1	398 (4.7) ± 23.3^{x}	392 (4.7) ± 26.8^{y}	400 (4.8) ± 23.4^{a}	395 (4.7) ± 14.3^{a}	369 (4.4) ± 32.7^{b}
Total starter until weaning, kg	39.7 ± 15.1	45.4 ± 18.5	37.5 ± 12.0	47.9 ± 19.9	46.7 ± 18.2^{x}	35.5 ± 9.8^{y}	32.5 ± 11.6^{y}
Growth variables							
Days to double weight (median)	75.7 (77) ± 13.2	72.6 (70.0) ± 12.9	78.5 (75) ± 11.7	69.5 (63) ± 12.9	69.9 (70.0) ± 11.3^{a}	77.7 (77.0) ± 9.2^{a}	90.3 (93) ± 13.1^{b}
Weaning weight, kg	83.4 ± 12.0	88.0 ± 13.5	85.6 ± 10.5	85.8 ± 15.2	88.8 ± 12.8^{a}	84.7 ± 10.1^{b}	71.4 ± 6.4^{c}
Days to 100 kg	107 ± 13.3	102 ± 14.9	106 ± 13.6	102 ± 14.8	101 ±13.6^{a}	105 ± 10.5^{a}	125 ± 2.7^{b}
Final weight, kg	101 ± 12.8	105 ± 13.8	104 ± 10.4	102 ± 15.9	105 ± 13.5^{a}	104 ± 10.8^{a}	88.5 ± 7.3^{b}
Pre-weaning ADG, kg/day	0.52 ± 0.12	0.58 ± 0.14	0.53 ± 0.11	0.57 ± 0.15	0.59 ± 0.12^{a}	0.52 ± 0.10^{a}	0.37 ± 0.07^{b}
Post-weaning ADG, kg/day	0.80 ± 0.12	0.74 ± 0.17	0.82 ± 0.12	0.72 ± 0.15	0.70 ± 0.12	0.75 ± 0.14	0.71 ± 0.11
Overall ADG, kg/day	0.58 ± 0.10	0.62 ± 0.11	0.59 ± 0.09	0.60 ± 0.12	0.62 ± 0.10^{a}	0.58 ± 0.08^{a}	0.46 ± 0.07^{b}

Within factors (i.e., starter treatment, sex or frequency of medical treatments), means with different superscripts^{a,b,c} differ at $P < 0.05$, or ^{x,y} at $P < 0.1$

ADG = Average daily gain

DISCUSSION

The two treatment groups studied in this experiment differed with regard to the type of pelleted calf starter provided; a commercially available cereal grain-based starter ('grain-based' or 'control') or a commercially available faba bean-based starter ('grain-free'). Under the conditions described in this experiment, no statistically significant differences in milk and starter intakes, weights, or ADG pre- or post-weaning were detected.

Pre-weaning growth

The grain-free starter used in this research (92% DM, 21% crude protein, 34.4% starch and sugar, 12.5 MJ/kg DM) delivered comparable protein, carbohydrate and energy levels to the control cereal grain-based pellet (91% DM, 21% crude protein, 38% starch and sugar, 12.5 MJ/kg DM). Nutritional analyses have shown faba bean has a DM content close to 90% and a starch content of around 400 g/kg (range 366-447 g/kg), giving it an energy value similar to common cereal grains (Crépon *et al.* 2010; Halmemies-Beauchet-Filleau *et al.* 2018; Meng *et al.* 2021). Calf diets with high amounts of starch are easily digested (Hill *et al.* 2016). The fermentation of carbohydrates such as starch and sugars stimulates rumen microbial proliferation and produces volatile fatty acids which promote the development of rumen epithelium thereby driving further increases in intake (see review by Diao *et al*., 2019; Hu *et al*., 2018). A review of 26 dietary treatments and 660 Holstein male calves found that ADG increased linearly with increasing starch concentration in dry feed (10-53% starch; Hu *et al*., 2018). As the grain-based and grain-free starter pellets in the present experiment contained comparably high amounts of readily fermentable carbohydrates (i.e., starch, sugar), I hypothesise that they similarly stimulated rumen development and consequently calf growth. Further research should assess rumen development on the faba bean-based grain-free pellet to confirm this.

The results of this experiment contrast with similar research on Wagyu × Friesian heifer calves (Burggraaf *et al.* 2020a; Khan *et al.* 2020). These studies offered starter pellet ad libitum until 5-weeks after the weaning of calves onto ryegrass pastures (weaning was at 10 weeks of age). Heifers offered a forage-based grain-free starter pellet had reduced growth and lower levels of circulating IGF-1 levels (insulin-like growth factor 1, supports growth) for the period that starter was provided, but experienced compensatory growth for the 20 weeks after starter was removed. Consequently no differences between liveweight, carcass composition or physiological indicators of nutritional state in the blood (e.g., plasma metabolites, IGF-1 levels) were observed from 41 weeks of age until slaughter at 26-30 months of age (Burggraaf *et al.* 2020a; Khan *et al.* 2020).

Starter composition is the most significant difference between the New Zealand research described above and the present study. The grain-free starter utilised in the studies of Burggraaf *et al.* (2020a) and Khan *et al.* (2020) was forage-based (ensiled alfalfa, 45% DM, 18.5% crude protein, 9.7 MJ/kg DM) with a lower dry matter and energy content compared to the cereal grain-based starter offered to the control calves (90% DM, 19.3% crude protein, 13.8 MJ/kg DM). The lower dry matter intake of grain-free calves, in combination with lower metabolizable energy, crude protein and non-soluble carbohydrates and higher fibre intakes, resulted in overall lower energy and nutrient supply, and consequently growth, compared to the control calves (Khan *et al.* 2020). These results should not be considered representative of calf performance on forage-based grain-free starter pellets *per se*. Terler *et al.* (2022) and Poier *et al.* (2022) supplemented pre-weaned Holstein-Friesian calves with high-quality ryegrass hay (11.2 MJ ME) or a medium-quality hay of mixed grass, clover and herbs (9.4 MJ ME), with or without a wheat and barley-based starter pellet (70:30 pellet:forage ratio). Energy and protein intakes, digestibility of organic matter, and growth rates were comparable between calves provided with only the high-quality hay and those supplemented with starter pellet, but calves provided only with the medium-quality hay had reduced feed intake and daily gains (Terler *et al.* 2022). The high-quality hay also improved rumination and the ruminal fermentation profile (i.e., butyrate proportion in VFA profile), and increased serum butyrate and cholesterol concentrations post-weaning, compared to calves offered cereal-based starter. These findings suggest greater metabolic capacity of the rumen epithelium in calves provided with the high-quality hay compared to those supplemented with a cereal-based concentrate (Poier *et al.* 2022; Terler *et al.* 2022).

In their review of the scientific literature on alternative feeds for ruminants, Halmemies-Beauchet-Filleau *et al.* (2018) suggested that the starch in faba beans has lower degradability in the rumen than cereal starch, which may reduce the risk of acidosis. While there were no statistically significant effects of starter type on calf weaning weights in the present experiment, data presented suggest a potential improvement in the weights of grain-free calves. Interpretation of these data is complicated by the health challenges experienced by calves in this study which produced greater variability in calf weights than expected, based on similar published research. For example, the coefficient of variation (a standardised measure of variability) for pre-weaning ADG and weaning weight were higher in the present experiment (23.6 and 14.5%, respectively) than in similar research on Holstein-Friesian calves (12.5 and 10.6%, respectively; Terler *et al*., 2022). Similarly, the standard error for the difference between treatments in weaning weights and ADG in this study were 3.5 and 0.036, respectively, which are higher than those reported by Burggraaf *et al.* (2020b) (Hereford × Holstein-Friesian calves; 2.4 and 0.012, respectively). The results of this experiment need to be confirmed with further research on a healthy cohort of calves.

Post-weaning growth

That the grain-free calves in the research of Khan *et al.* (2020) and Burggraaf *et al.* (2020a) experienced compensatory growth post-weaning suggests a forage-based diet may better prepare the rumen for weaning onto pasture. Cristobal-Carballo *et al.* (2021) found a calf diet rich in fibre increased the proportion of cellulose degrading microorganisms in the rumen whereas a cereal-based concentrate supported propagation of bacteria that utilise soluble carbohydrates, like starch and sugars. A substantial body of published research demonstrates the positive effects of supplementing calves with forage on rumen pH, thereby reducing the risk of sub-clinical acidosis, increasing intake and supporting growth in rumen capacity (Khan *et al.* 2011; Castells *et al.* 2013; Kim *et al.* 2016; Maktabi *et al.* 2016; Nemati *et al.* 2016; Lin *et al.* 2018; Poier *et al.* 2022), while also improving rumen motility, blood flow to the rumen mucosa and volatile fatty acid absorption (reviewed by Khan *et al*., 2016).

Post-weaning calf weights did not differ in this experiment. One interpretation of this is that the grain-free calf starter did not significantly alter the rumen environment compared to the grain-based starter. Anecdotally, the rumen of a calf from the grain-free treatment that died 7-days postweaning appeared to be well developed (Appendix 6). Differences in methodology between the present experiment and that of Khan and colleagues (2020) may also explain the contrasting results. The weights of calves in this experiment were recorded for 3-weeks post-weaning and starter pellet (grain-based or grain-free) continued to be provided daily. By contrast, the compensatory growth of calves provided a forage-based grain-free diet observed by Khan *et al.* (2020) was recorded over a period of nearly 30 weeks and commenced only once supplementary pellet ceased at 5-weeks post-weaning. Further research is required to understand the short and long-term effects of a faba bean grain-free pellet on ruminal microbiota, volatile fatty acid profile and rumen development.

Health

Health had a significant effect on calf intake and weights in this experiment; the sicker the calves were, the less milk and pellet they consumed, and the lower their growth and weights. The effect of pre-weaning health on weights persisted into the post-weaning period. The negative impacts of calf disease on growth and appetite are well documented (e.g., Roth *et al*., 2009), and other studies also report that the comparatively low weights of sick versus healthy dairy × beef calves persist post-weaning (Johnson *et al*., 2019). Thus, at least in this experiment, poor health was more likely to extend the time to weaning and increase rearing costs than the grain-free requirement of Greenham's dairy beef program.

Optimising the care and management of dairy beef calves so that they remain in a high state of health and welfare will increase the likelihood of producing a high-quality animal that quickly meets weaning credentials. Research from Australia and abroad suggests there is a risk of dairy beef calves receiving a lower standard of care on some farms than replacement heifers. For example, the proportion of Australian farms that always feed colostrum is twice as high for dairy heifers than for dairy bull calves (34 vs 62%), while dairy × beef calves are three times more likely to experience failed passive transfer of immunity (**FPTI**) than are heifer calves (Vogels *et al.* 2013). Other recent Australian research found that 50% of bobby calves (85% of which were male) blood sampled at exsanguination at the abattoir had suboptimal passive transfer of immunity, with FPIT identified in

36% of the calves (Roadnight *et al*., 2022). These authors also reported that 10% of the variability in successful passive transfer was related to the farm of origin; one of the 82 farms sampled had successful passive transfer for all calves whereas nearly 90% of calves on another had FPIT (Roadnight *et al*., 2022). The present experiment assessed passive transfer of immunity in 12 healthy appearing calves at 2-days of age; 20% failed to achieve affective transfer of immunity. Similar challenges are reported in countries with more developed dairy beef supply chains. In Canada 18% of young male calves arrive at the rearing facility in an emaciated state and 12% have clinical signs of dehydration (Renaud *et al.* 2018a; Renaud *et al.* 2018b). In total, 10% and 17% of farms do not provide colostrum or the same quantity of feed to male calves as to heifer calves respectively (Renaud *et al.* 2017). Comparable results are reported in the USA (Shivley *et al.* 2019).

A best-practice guide for the rearing of dairy-beef calves could prevent a two-tiered rearing model in Australia, where dairy-beef calves receive a lower standard of care than dairy heifer calves. Significant research has been undertaken to advise the rearing of replacement heifers. Much of this research will be transferrable from dairy heifers to dairy-beef calves. For example, protocols around colostrum management to achieve adequate transfer of immunity will be equally important to dairy beef animals as they are to dairy heifer calves (i.e., Quality, Quickly, Quantity, and sQueaky clean – Dairy Australia, 2017). Relationships between failed transfer of immunity, reduced feed intakes and growth are well established (e.g., see review by Roche *et al*., 2015). Transition milk provides a further opportunity to improve calf health and production. Providing transition milk for around 4 days after initial colostrum feeding stimulated intestinal development and improved the health and growth of Holstein bull calves (Van Soest *et al.* 2022) yet thousands of litres of transition milk are discarded every day on Tasmanian dairy farms (Snare 2020).

Feeding calves restricted milk volumes has traditionally been used to encourage the early intake of solid feed, promote rumen development, and minimise labour and feeding costs. The benefits of increased milk volumes pre-weaning on long-term heifer productivity have been demonstrated (see review by Roche *et al*., 2015). Although limited research is available in dairy × beef animals, the published work to date suggests a similar relationship between increased milk volumes pre-weaning and long-term productivity. Burggraaf *et al.* (2020b) observed improved growth in Hereford x Holstein-Friesian heifer calves provided with 8L milk/day for 9 weeks then reduced to 4L/day until weaning at 12 weeks, compared to calves on an early weaning program (4L milk/day for 5 weeks, reducing to 2L/day until weaning at 7 weeks, plus ad lib starter pellet). Although the calves on high milk volumes had no access to pelleted starter (but they did have access to pasture from 1 week of age), they were 7 kg heavier at 12 weeks of age, remained heavier at 7 months of age and reached slaughter credentials 22 days earlier than low-volume/early weaned calves (Burggraaf *et al.* 2020b). Johnson *et al.* (2019) similarly found dairy × beef calves provided with increased milk volumes were larger at weaning and remained bigger at 6-months of age. The rumen of young calves is not developed enough for solid feed digestion. Thus, increasing the energy intake of dairy × beef calves via higher milk volumes over the first approximately 4-5 weeks of life is an efficient way of improving growth and does not negatively affect gastro-intestinal development or rumen function (McCoard *et al.* 2014; Schäff *et al.* 2018; Burggraaf *et al.* 2020b). In combination with the later weaning ages (>10 weeks) typical in Australian calf rearing systems, this management provides opportunity for the rumen to adequately develop while supporting improved growth rates, even when calves are provided with forage as the only solid feed source (e.g., McCoard *et al*., 2019; Burggraaf *et al*., 2020b).

Burggraaf *et al.* (2020b) found that feed quality after weaning had a greater impact on the lifetime performance and growth of Hereford × Holstein-Friesian calves than the pre-weaning diet (i.e., quantity and duration of milk feeding). Calves weaned onto a high-quality (irrigated, perennial ryegrass and white clover) pasture grew twice as fast from 3-7 months of age, were 31 kg heavier at 7 months, and were slaughtered 61 days earlier than those on low quality pasture (non-irrigated). Other research demonstrates that achieving high levels of animal performance at pasture reduces the need for concentrate supplementation and reduces green-house gas emissions per kg of beef produced (Murphy *et al.* 2018). These results emphasise the importance of maintaining quality nutrition post-weaning to reduce finishing time on a grass-fed diet.

CONCLUSIONS

This experiment found no effects of a faba bean-based grain-free calf starter pellet on the pre-weaning growth, weaning weights or post-weaning growth of dairy × beef calves. The cereal grain-based and grain-free starter pellets used in this experiment contained comparably high levels of readily fermentable carbohydrates and so may have similarly stimulated rumen development and consequently calf growth. Further research should assess rumen development on the faba bean-based grain-free pellet to confirm this. Health affected calf intake and weights in this experiment; the sicker the calves were, the less milk and pellet they consumed, and the lower their growth and weights. Thus, in this experiment, poor health was more likely than grain-free pellets to extend the time to weaning and increase rearing costs. The results of this experiment should be confirmed in a healthy cohort of calves.

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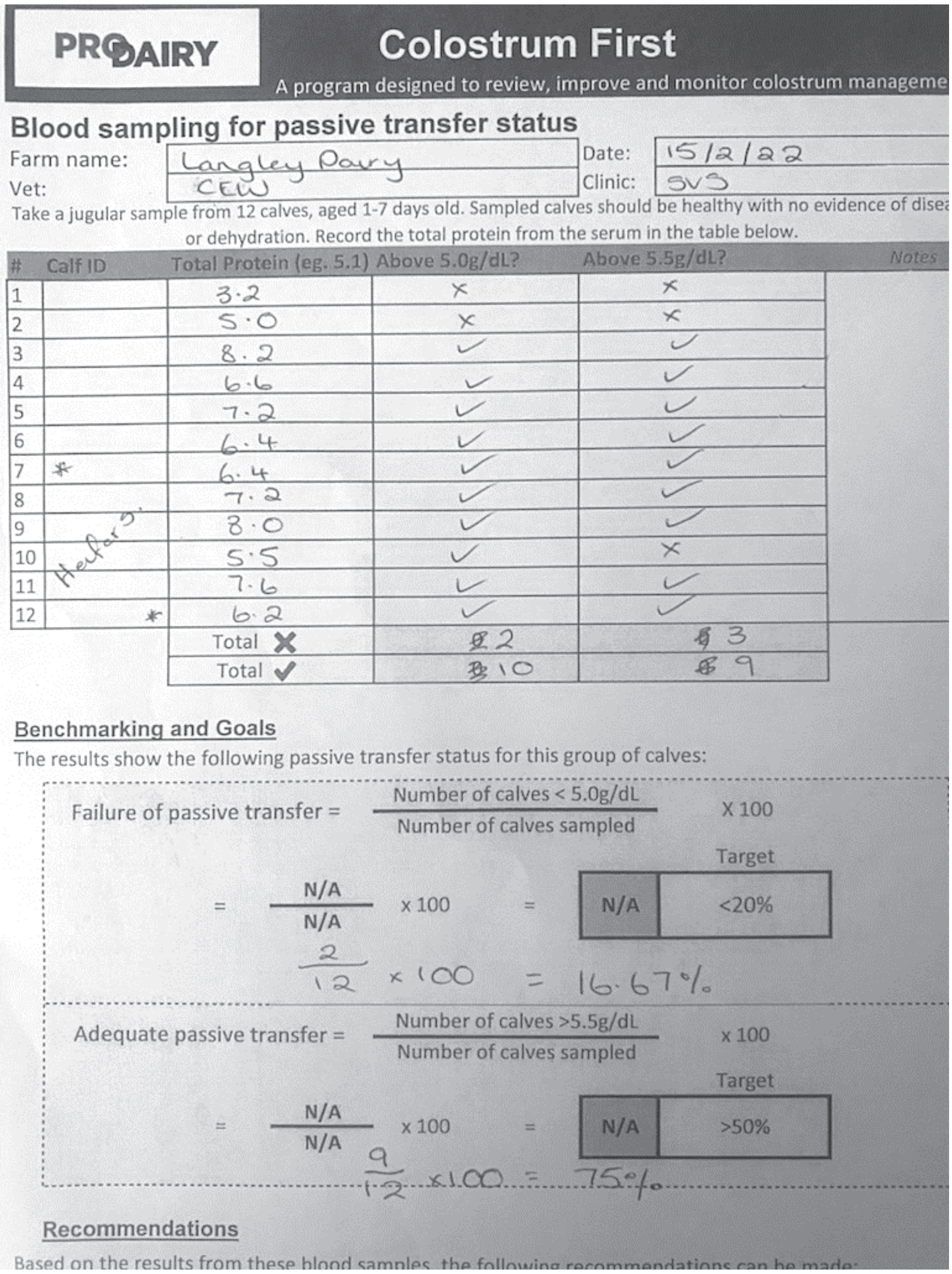
APPENDICES

Appendix 1 Results from the assessment of total blood protein taken from 20% of calves



PRODAIRY

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Blood sampling for passive transfer status

Farm name:	Langley Dairy	Date:	15/2/22
Vet:	CEW	Clinic:	SVS

Take a jugular sample from 12 calves, aged 1-7 days old. Sampled calves should be healthy with no evidence of disea or dehydration. Record the total protein from the serum in the table below.

#	Calf ID	Total Protein (eg. 5.1)	Above 5.0g/dL?	Above 5.5g/dL?	Notes
1		3.2	✗	✗	
2		5.0	✗	✗	
3		8.2	✓	✓	
4		6.6	✓	✓	
5		7.2	✓	✓	
6		6.4	✓	✓	
7	*	6.4	✓	✓	
8		7.2	✓	✓	
9	Heifers	8.0	✓	✓	
10		5.5	✓	✗	
11		7.6	✓	✓	
12	*	6.2	✓	✓	
		Total ✗	2	3	
		Total ✓	10	9	

Benchmarking and Goals

The results show the following passive transfer status for this group of calves:

Failure of passive transfer = $\frac{\text{Number of calves} < 5.0\text{g/dL}}{\text{Number of calves sampled}}$ X 100

= $\frac{N/A}{N/A}$ x 100 = N/A | Target <20%

$\frac{2}{12} \times 100 = 16.67\%$

Adequate passive transfer = $\frac{\text{Number of calves} > 5.5\text{g/dL}}{\text{Number of calves sampled}}$ x 100

= $\frac{N/A}{N/A}$ x 100 = N/A | Target >50%

$\frac{9}{12} \times 100 = 75\%$

Recommendations

Based on the results from these blood samples, the following recommendations can be made:

Appendix 2 Details of pasture allocation and estimated pasture intakes over 5-weeks post-weaning

Allocation[1]	Treatment	Days in allocation	Paddock	Pre-grazing biomass (kg pasture DM/hectare)	Post-grazing biomass (kg pasture DM/hectare)	Estimated pasture intake per calf (kg DM/day)
Allocation 1	Control	3	1	3062	2334	1.3
	Grain-free	3	1	3068	1998	1.9
Allocation 2	Control	4	1	3076	2348	1.3
	Grain-free	4	1	3006	2320	1.4
Allocation 3	Control	3	1	3510	1802	1.7
	Grain-free	3	1	2880	2600	0.7
Allocation 4	Control	3	1	2908	1956	2.9
	Grain-free	3	1	3048	2278	1.8
Allocation 5	Control	3	1	2894	1900	3.1
	Grain-free	3	1	3048	2194	2.0
Allocation 6	Control	5	1	2026	2026	0.0[2]
	Grain-free	5	1	2180	2208	0.13[2]
Allocation 7	Control	14	2	3902	2796	1.2
	Grain-free	14	2	3958	2826	1.2

[1]Calves were strip-grazed (in their separate treatment groups) from allocations 1-5, as they were trained to electric fencing and experienced with grazing conditions. From allocation 6 calves were provided with access to the entirety of paddock 1. During Allocation 7 calves were provided with access to the entirety of paddock 2 for the remaining 14 days of the experiment.
[2]An error may have occurred while using the rising plate meter.

Appendix 3 Health monitoring criteria for calves

Category	Observation	Description	Intervention
Vigour	Bright	Normal: bright, alert, responsive	1
	Quiet	Dull but responds to stimulation	2
	Dull	Depressed, slow to stand or reluctant to lie down, little to no response to stimulation	3
Discharge	Clear	Normal	1
	Discharge	Small to moderate amount of ocular and/or unilateral/bilateral cloudy mucus discharge	2
	Severe discharge	Heavy ocular discharge and/or bilateral mucopurulent discharge	3
Cough	No cough	No cough	1
	On movement	Movement induced single to repeated coughs, or occasional spontaneous cough	2
	Frequent	Repeated spontaneous coughs	3
Scours	Clean	Clean rump	1
	Dirty	Some fecal soiling of rump	2
	Wet	Rump heavily soiled with fecal matter	3
Feeding	Normal	No refusal, observed feeding unassisted or records show calf has fed within 24 hours	1
	Reduced	Slow consumption observed, may require assistance to begin feeding, records show refusal of up 0 to 50% of milk offered in last 24 hours	2
	Inappetence	Observed feed refusal even when assisted, records show calf hasn't fed in 12-24 hours	3
Naval	Dry	Normal	1
	Swelling	Slightly enlarged, not warm or wet, does not appear painful/hot/discharge	2
	Discharge	Swelling with pain and/or heat and/or discharge	3
Bloating	Normal	No bloating	1
	Bloated	Slight bloating, normal movement, no obvious discomfort	2
	Severe bloat	Significant bloating with discomfort	3

Appendix 4 Estimated marginal means (i.e., means from linear models which accounted for start weight and pen, EMM) ± standard error of the mean. In the case of total milk consumed (L), where a transformation was used prior to analysis, the transformed EMM is presented with backtransformed EMM in parenthesis. Days to double weight was not subject to linear modelling and so is not included in this table.

	Starter treatment		Sex		Frequency medical treatments		
	Control	GF	M	F	None	Once	Multiple
Intake variables							
$y = \log_{10}(k - \text{total milk consumed})$[1]	1.5 ± 0.16 (392 L)	1.4 ± 0.15 (402 L)	1.3 ± 0.11 (403 L)	1.6 ± 0.14 (389 L)	1.2 ± 0.11 (409 L)	1.4 ± 0.15 (397 L)	1.8 ± 0.17 (367 L)
Total starter, kg	38.1 ± 7.1	39.6 ± 6.6	35.9 ± 5.0	42.2 ± 6.4	46.0 ± 4.8	34.6 ± 6.6	34.5 ± 7.7
Growth variables							
Weaning weight, kg[2]	21.1 ± 13	25.8 ± 13.2	23.3 ± 13.6	23.2 ± 12.5	31.5 ± 12.9	23.2 ± 13.6	12.3 ± 13.3
Days to 100 kg[2]	168 ± 16.4	165 ± 16.9	170 ± 17.0	162 ± 16.1	159 ± 16.2	166 ± 17.0	185 ± 17.4
Final weight, kg[2]	38.6 ± 14.2	40.3 ± 14.6	39.2 ± 15.0	39.6 ± 13.6	46.1 ± 14.1	42.3 ± 14.7	26.6 ± 14.8
Pre-weaning ADG, kg/day	0.47 ± 0.03	0.53 ± 0.03	0.51 ± 0.02	0.48 ± 0.04	0.59 ± 0.02	0.50 ± 0.04	0.37 ± 0.05
Post-weaning ADG, kg/day	0.79 ± 0.04	0.75 ± 0.04	0.81 ± 0.03	0.73 ± 0.04	0.78 ± 0.03	0.81 ± 0.05	0.74 ± 0.07
Overall ADG, kg/day	0.55 ± 0.03	0.57 ± 0.02	0.57 ± 0.02	0.55 ± 0.03	0.62 ± 0.02	0.59 ± 0.03	0.44 ± 0.04

[1]Where k = largest possible value for total milk consumed plus 1
[2]Start weight was included as a covariate in these analyses

Appendix 5 Calf mortalities and removals from the trial.

Calf	Date	Day	Cause of death/reason for removal
49	Died 20th Feb	3	Sudden death – necropsy confirmed pneumonia with no obvious cause.
37	Died 22nd Feb	5	Died due to illness associated with cryptosporidium infection. Calf has been in the sick pen with intensive care and being treated with fluids, trisoprim and alamycin for 3 days.
13	Died 22nd March	33	Died aspirated while being tubed fluids. It was receiving intensive care in the sick pen after becoming unwell with bloody scours. Samples taken later tested positive to coccidia.
413	Died 28th March	39	Died due to illness associated with coccidiosis. Calf was in the sick pen receiving treatment of fluids, trisoprim and flunixin. Death was unexpected as the calf had earlier in the day been standing and feeding normally.
27	Removed 5th May	77	Removed from trial. Chronic health issues characterised by low weight gains, intermittent poor appetite, low vigour, high temperatures. Pestivirus negative. Veterinary inspection 27th April suggested immunosuppression, chronic gut and possibly lung infections. Individualised care with extended rearing to be completed by third party. Data removed from trial.
15	Removed 15th May	87	Removed from trial. Persistent low weight gains. Calf was only 50 kg the week of weaning, despite good milk intakes (confirmed as the calf was bottle fed all trial). Individualised care with extended rearing to be completed by third party. Data removed from trial.
113	Died 23rd May	95	Calf was found dead in the paddock at 7 days post-weaning. Necropsy concluded cause of death was subacute bronchopneumonia. Calf had been treated multiple times during pre-weaning period.

Appendix 6 The rumen of a calf from the grain-free treatment that died 7-days post-weaning. The rumen appears to be well developed.