Factors affecting early concentrate uptake by calves

PD Muir, BC Thomson* and NB Smith

On-Farm Research, PO Box 1142, Hastings

**Corresponding author:* Email: bev@on-farm.co.nz

Abstract

Early solid food intake is key to a successful early rumen development system. In NZ, specialist bull-calf rearers tend to feed four-day-old calves restricted milk, *ad lib* pellets and wean early (5 to 6 weeks). A range of experiments examined the effect of protein %, feed form and the effect of changing protein source in older calves. There was no difference between 16% and 20% protein pellets in the first three weeks but between weeks three and six, feed intakes and liveweight gains were higher on 20% protein pellets (P<0.05). Weaning live weights were higher on a customised pellet (51.5% maize, 20.0% peas, 20.0% soy bean extract 48, 5% molasses, 1.5% limestone, 1.0% soybean oil, 0.8% salt, calf vitamin mineral premix (0.01%), Bovatec (0.006%) and Rumasweet palatant (0.00002%)) than on a commercial pellet (68.9 vs 64.8 kg, P<0.05). Feeding the customised formulation either in roller-milled, hammer-milled or pelleted form did not affect feed intake or liveweight gain. In weaned calves well-adjusted to consuming concentrates, substituting a commercial meal with palm kernel significantly reduced feed intake when fed at 60% of the ration whilst copra meal substitution significantly reduced intake at 40% in calves accustomed to eating pellets. Pellet composition had a greater impact on feed intakes and growth rate than did the form in which the feed was offered.

Keywords: calf; copra meal; palm kernel; protein content; artificially reared

Introduction

Because of the low margins associated with the rearing of dairy bull calves in New Zealand, low-cost, reduced milk systems along with concentrate feeding and early weaning have become part of specialist bull calf rearing systems. Early intake of calf pellets is critical to the early weaning process involved in these systems due to the nutrient density of these products and the acceleration of rumen development through the intake of solid feeds (Henrichs 2005). Early rumen development enables early weaning onto pasture and since the cost per unit of energy is higher for milk ingredients than pasture, the sooner calves can start consuming pasture and be weaned off milk, the lower the cost of rearing. Calves in early rumen-development systems tend to be purchased at around four-days of age and sold at 100 kg at 12 weeks of age (end of October) and cost reductions need to be balanced with effects on calf growth rate. Calves on a once-a-day early rumen-development system are weaned when intake of solid feed reaches 1 kg/day, usually around six weeks of age (Muir et al. 2002). To achieve these solid feed intakes in young naïve calves, meals need to be highly palatable (Miller-Cushon et al. 2014).

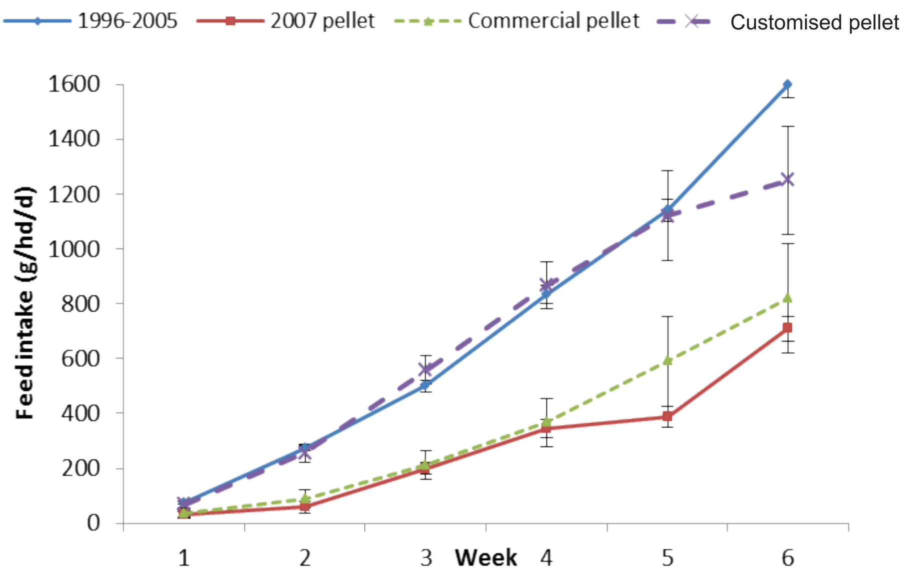
Traditionally, calves raised using New Zealand early rumen-development systems are fed 20% protein calf pellets before weaning, then fed a lower-cost 16% protein pellet after weaning. Anecdotally, some calf rearers are feeding calf meals with 16% crude protein throughout the rearing phase. Whilst dairy farmers rear their heifer replacements on whole milk, most New Zealand bull-calf rearers feed casein-based milk replacer (Thomson et al. 2018). A laboratory analysis of six milk different calf milk replacers brands showed average crude protein contents of 26.4% (Muir, unpublished data). Since milk replacers typically make up a 50% of the diet (on a DM basis) on an early rumen-development system, it is possible that feeding a lower protein content pellet could still provide an average protein content in the diet of 21%. This is still in excess of the 18% dietary protein in pellets suggested by Khan et al. (2016).

Relatively high and consistent intakes of calf pellets were recorded by the authors in previous experiments between 1996 and 2005 but intakes declined by around 50% in a 2007 experiment (Figure 1). Potential reasons for the decline in intakes include change in type of ingredients used, changes in protein and energy content or old, stale and less palatable feed. Unfortunately, labelling on bags of calf pellets is poor, with only minimum specifications for protein content and typically stating that the product could be made from some or all of a long list of ingredients pre-printed on the bags. The lack of detailed information on New Zealand calf pellets makes it difficult for rearers to make an informed purchase decision. Moreover, least-cost formulations and limitations on supplies of ingredients mean that composition of calf meals can vary between batches or across the season as the availability and price of some components change.

Whilst many calf rearers purchase commercial pellets, others mix their own feed and offer it as a loose meal. The pressing of loose ingredients into a pellet is an additional cost (local mills charge $60/tonne) and this increases the overall cost of rearing. There are, however, few data on whether the form (roller-milled, hammer-milled, pelleted) in which feed is presented to calves impacts on voluntary feed intakes and growth rate of calves.

Palm kernel and copra meal have both been utilized as low-cost protein sources in New Zealand and have

Figure 1. Average feed intakes in calves fed commercial pellets from seven trials between 1996 and 2005 compared with feed intakes from a 2007 trial. Dotted lines indicate results from Experiment 2 of the pilot trial comparing commercial pellets with a customised ration.



been imported in large quantities for sale especially to the dairy industry. It is possible that these products have been incorporated into calf feeds and may have a role in reduced palatability and decreased feed intakes.

This work reports on a series of experiments which examined the effect of feed type on calf feed intakes and growth rates by comparing:

(1) The growth rate of calves fed 20% or 16% protein pellets pre-weaning
(2) The feeding of a customised pellet with known high-quality ingredients pre-weaning against a commercial pellet which had previously been associated with low feed intakes
(3) The form in which solid feed (roller-milled, hammer-milled, pelleted) is offered to young calves on liveweight gain pre-weaning
(4) The intake of diets containing copra meal or palm kernel on feed intake in weaned calves.

Materials and methods

Calves for Experiment 1-2 were purchased as four-day-old calves from the dairy industry and transported to the Hawkes Bay. They were tagged and weighed on arrival and allocated to treatments. Treatments were balanced by live weight and arrival date. Calves were fed 1 litre of calf milk replacer (CMR 200g/l) twice a day for the first four days and then 2.5 l of CMR (200g/l) in compartmental feeders. Calves were supervised at each feeding to ensure each calf drank its allowance. Clean water was available *ad libitum* in each pen. Calves were weighed prior to weaning. The weaning criterion was that an individual calf had put on at least 20 kg since arrival.

Experiment 1. Feed intake in young calves of pellets containing 20% and 16% crude protein

In this experiment, two groups of 120 Friesian bull calves purchased at four days of age from commercial dairy farms and were offered commercial pelleted rations containing either 20% or 16% protein (Harvey Farms, Wanganui). Pellets were analysed by Hill Laboratories (Hamilton) and found to contain 20.1% and 16.2% crude protein for the 20% and 16% pellets respectively. On arrival, calves were tagged and weighed. Calves were penned in groups of eight, with groups balanced for arrival weight and fed 500 g of a commercial milk replacer (Bounce, Fonterra, Auckland) in 2.5 litres water per head per day. Calves were fed once a day using compartmental feeders and monitored during feeding to ensure each calf drank its full allowance. Calves were checked for scouring and any other health issues at each feed. Pellets were fed *ad libitum* in a group feeder from Day 1. Fresh pellets were added daily and refusals measured weekly to determine pellet intake for each pen. Calves were weighed on arrival (0 weeks) and again at three and six weeks after arrival. Calves that were not weaned at six weeks were re-weighed at eight weeks and all but three were weaned. Weaning criteria were that calves weighed more than 60 kg and had gained at least 20 kg since arrival. Milk feeding was stopped abruptly once individual calves met the weaning criteria. After milk feeding stopped, calves were kept indoors for three days and fed *ad libitum* on the same pellets they had been fed prior to weaning.

Experiment 2. Evaluation of a commercial calf pellet

A customized pelleted calf ration was developed using 51.5% maize, 20.0% peas, 20.0% soy bean extract 48, 5% molasses, 1.5% limestone, 1.0% soybean oil, 0.8% salt plus small amounts of calf vitamin mineral premix (0.01%), Bovatec (0.006%) and palatability enhancer (Rumasweet palatant 0.00002%). This ration was then compared in an on-farm trial against a commercial pelleted ration marketed as containing 20% crude protein and which had been associated with low feed intakes and poor calf growth rates the previous year. Pellets were analysed and found to have 20.6% and 20.4% crude protein (Hill Laboratories, Hamilton), for the formulated and commercial rations respectively. Twenty, four-day old Friesian bull calves were trucked from the Waikato region and tagged and weighed on arrival. Calves were allocated to four pens of five calves and balanced for live weight. Two pens of calves were each fed either the commercial ration or the customised ration. Calves were fed once daily with 500 g of a commercial milk replacer (Ngahiwi Farms, Auckland) in 2.5 litres water per head. Calves were fed using compartmental feeders and monitored during feeding to ensure each calf drank its full allowance. Calves were checked for scouring and any other health issues at each feeding. Pellets were fed *ad libitum* in a single covered feeder per pen from Day 1. Fresh pellets were added daily with feed refusals recorded weekly and intakes calculated. Fresh water was freely available. Calves were weighed on arrival (0 weeks) and at three weeks and six weeks of age. At six weeks, calves which had put on 20 kg live weight were weaned. The remainder remained on milk until they reached the weaning criteria but experimental data were only analysed up to weighing at six weeks of age.

Experiment 3. Effect of meal presentation on feed intake

In this study, 194 four-day-old Friesian heifer and bull calves were sourced from commercial dairy farms, tagged, weighed on arrival and allocated to 15 pens of 12-13 calves. Calves arrived in three batches each a week apart. On arrival, calves were weighed and tagged. Within each batch, pens were randomly allocated to one of three treatment groups with five pens per treatment in total. Treatment groups were balanced for live weight and batch. The same customised feed formulation from Experiment 2 was offered either in pelleted, hammer-milled or roller-milled form. Calves were each fed 3.5 litres fresh transition milk daily in compartment feeders and the concentrate feed was offered *ad libitum* to each pen in a covered feeder from Day 1. Milk feeding was supervised to ensure each calf drank its full milk allowance. Calves were checked for scouring and any other health issues at each feed. Fresh feed was added daily and refusals measured weekly and feed intakes calculated. Fresh water was always available. Calves were weighed on arrival (week 0) and again at six weeks of age and calves that had increased in weight by 20 kg were weaned. After weaning off milk, all calves were run together and offered the pelleted ration.

Experiment 4. Effect of increasing proportion of palm kernel and copra meal on post-weaning feed intakes of calves

This trial used seventy-two weaned Friesian bull calves aged eight weeks and which had been reared on a once-a-day milk feeding system as described in Experiment 1. Calves had been fed on 20% protein pellets (Topcalf, Harvey Farms, Wanganui) and had been kept indoors after weaning. Calves were randomized into four treatment groups and balanced for live weight. Copra meal was substituted into the ration at 0, 20, 40 and 60% of the total feed on offer and feed intake measured every two days over a nine-day period. Calves were then re-randomized into four groups and placed on 20% protein pellets for two days. Palm kernel meal was substituted into the ration at 0, 20, 40 and 60% of the total feed on offer for nine days. Daily feed intake was measured every two days. Straw and fresh water were freely available through both treatment periods, but the amounts were not measured.

Statistical analysis

Experiment 1was analysed using a Generalised Linear Model in Minitab with two treatment levels – 16% and 20% protein pellets. Pen was used as the experimental unit for feed intakes. Experiment 2 was analysed using a Generalised Linear Model in Minitab with two treatment levels – customised formulated versus a commercial 20% protein pellet. Pen was used as the experimental unit for feed intakes and initial live weight fitted as a covariate for the liveweight data. Experiment 3 was analysed using a Generalised Linear Model in Minitab with three treatment levels – pelleted, hammer-milled and roller-milled plus breed and sex of calf. Arrival live weight and batch were fitted as covariates for live weight. Batch was fitted as a covariate for live weight gain and feed intake. Pen was used as the experimental unit for feed intakes. Experiment 4 was analysed using a Generalised Linear Model in Minitab with four treatment levels (0, 20, 40, 60%) and pen used as the experimental unit. The data were analysed both by individual day and as the total amount eaten over the period. Copra meal and palm kernel data were analysed as separate experiments.

This work was approved by the Agresearch Grasslands Animal Ethics Committee (AE 10534,10650 and 11534).

Results

Experiment 1

Calves fed the 20% pellets ate more from weeks three to six and grew faster before weaning than did the calves fed on the 16% protein pellets (Table 1) resulting in more calves weaned at six weeks in the 20% protein pellet treatment (78.8%) than in the 16% protein pellet treatment (52.6%). Calves fed 20% protein pellets ate an average of 184 g/d over the first three weeks and 918 g/d from three to six weeks. Calves fed the 16% protein pellets consumed an average of 164 g/d from zero to three weeks and 738 g/d over the second three weeks.

Experiment 2: Comparison of a customised formulated pellet with a commercially available pellet.

Calves fed the formulated pellets ate 29.3 kg over the six weeks of the experiment, whereas the calves fed the commercial pellet ate 14.8 kg over the same period (Table 2). These means were not significantly different (SEM 1.19 kg P=0.11). Feed intake of the formulated ration was 1.1 kg/head/day at the end of week 5 while on the commercial pellet the intake was only 0.59 kg/day/day (Table 2).

When initial weight was fitted as a covariate, the calves on the formulated pellets were heavier than the calves on the commercial pellets (68.9 vs 64.8 kg, P<0.03).

Experiment 3: Effect of diet form on liveweight gain and feed intake

The form in which the diet was offered to the calves

Table 1 Live weight, weaning percentage and solid food intake of Friesian bull calves fed commercial pellets containing either 20% or 16% protein from four days of age to weaning at six weeks of age.

	20% Protein		16% Protein		
	Mean	SEM	Mean	SEM	P
Number of animals	60		60		
Start weight (kg)	43.1	0.39	43.6	0.41	0.36
3 week weight (kg)	50.6	0.32	49.3	0.32	0.07
6 week weaning weight (kg)	67.4	0.51	63.2	0.51	0.001
Calves not weaned at 6 weeks (%)	21.2		47.4		
Intake (kg/hd/d)					
Week 1	0.066	0.005	0.064	0.005	0.77
Week 2	0.167	0.010	0.160	0.010	0.66
Week 3	0.320	0.020	0.268	0.020	0.07
Week 4	0.680	0.032	0.519	0.032	0.001
Week 5	0.963	0.040	0.779	0.040	0.003
Week 6	1.110	0.050	0.918	0.050	0.01
Total (kg/hd)	23.1	0.89	19.0	0.89	0.003

Table 2 Feed intake of Friesian bull calves fed a customised formulated pellet or a commercial 20% protein calf pellet from four days of age to weaning at six weeks of age.

Week	Formulated		Commercial		P
	Mean	SEM	Mean	SEM	
1	0.069	0.011	0.035	0.011	0.16
2	0.255	0.033	0.0894	0.033	0.08
3	0.557	0.052	0.212	0.052	0.04
4	0.867	0.087	0.367	0.087	0.06
5	1.12	0.165	0.59	0.165	0.15
6	1.32	0.198	0.82	0.198	0.2
Total (kg/calf)	29.3	3.63	14.8	3.63	0.11
Number of animals	10		10		

had no significant effect on feed intake, pre-weaning growth rate (0.55, 0.56 and 0.54 kg/head/day for pelleted, hammer-milled and roller-milled diets respectively P > 0.40) or post-weaning growth rate (0.69, 0.66 and 071 kg/head/day for pelleted, hammer-milled and roller-milled diets respectively P > 0.30). Intakes between pens and batches of calves were highly variable (Table 3).

Experiment 4: Effect of copra meal and palm kernel on the palatability of post-weaning calf diets

From eight weeks of age, intakes rose from 2.72 kg/day to 3.21 kg/day in the group fed entirely on calf pellets (Table 4). Replacing 20% of the calf pellet ration with copra had no effect on calf intake, whereas replacing 40% and 60% of the pellet ration with copra meal decreased calf intake. Palm kernel tended to reduce feed intake, but this was only significant at the 60% substitution level (Table 4).

Discussion

In New Zealand, many specialist bull-calf rearers use a restricted milk system, *ad libitum* pellets and then weaning starting at five weeks of age. Current practice under these restricted milk feeding systems is to feed calves on 18-20% protein meal prior to weaning and then feed 16% protein pellets after weaning which typically occurs at between 5 and 7 weeks of age (Muir et al, 2002). Protein tends to be the most expensive component of the ration here, so rations with lower protein contents are usually cheaper. There is anecdotal evidence that a number of bull-calf rearers are feeding lower-protein calf pellets throughout the rearing phase to reduce costs. However, there are no comparable data on calf liveweight gain. Overseas recommendations suggest that calf diets should contain 18% crude protein on a DM basis (Hill et al. 2005, Khan et al. 2016). Kertz et al. (2017) suggested that 16% crude protein was adequate

Table 3 Daily calf meal intakes (kg/d) of Friesian bull and heifer calves when fed the same diet manufactured in three different forms from four days of age to weaning at six weeks of age.

	Form						
	Pellet		Hammer milled		Roller milled		
	Mean	SEM	Mean	SEM	Mean	SEM	P
Number of calves	65		63		65		
Arrival wt (kg)	36.7	1.87	36.4	1.95	34.8	1.90	0.10
Weaning wt (kg)	65.2	1.69	65.4	1.77	64.9	1.75	0.91
Age weaned (d)	42.4[ab]	0.97	41.4[a]	1.01	42.7[b]	1.00	0.02
Pre-weaning growth (kg/d)	0.55	0.040	0.56	0.041	0.54	0.041	0.42
Final wt (kg)	98.5	3.23	97.2	3.37	97.7	3.33	0.72
Age final (d)	89.1	1.74	89.2	1.82	88.2	1.80	0.54
Post-weaning growth (kg/d)	0.69	0.066	0.66	0.069	0.71	0.069	0.31
Average growth rate (kg/d)	0.63	0.037	0.619	0.039	0.63	0.038	0.75
Intake (kg/hd/d)							
Week 1	0.114	0.028	0.096	0.28	0.136	0.031	0.65
Week 2	0.172	0.028	0.156	0.028	0.190	0.037	0.75
Week 3	0.296	0.036	0.271	0.036	0.295	0.040	0.86
Week 4	0.475	0.037	0.502	0.037	0.530	0.416	0.65
Week 5	0.715	0.051	0.654	0.051	0.803	0.056	0.21
Week 6	0.818	0.073	0.963	0.073	1.052	0.082	0.15
Total (kg/hd)	18.1	1.45	18.5	1.44	21.0	1.84	0.42

Columns with in a row with different superscript (abc) are significantly different (P< 0.05)

Table 4 Intake of weaned Friesian bull calves fed concentrate with different proportions of Copra and Palm kernel from eight and ten weeks of age respectively.

		Day					
	Number	1	3	5	7	9	Total
Copra %							
0	18	2.72	2.59^{b}	2.83^{b}	3.01^{b}	3.21^{b}	16.9^{b}
20	18	2.72	2.42^{b}	2.81^{b}	3.00^{b}	3.11^{ab}	16.4^{b}
40	18	2.28	2.02^{a}	1.94^{a}	2.22^{a}	2.63^{a}	13.4^{a}
60	18	2.13	1.74^{a}	2.12^{a}	2.35^{a}	2.62^{a}	13.4^{a}
SEM		0.218	0.131	0.183	0.136	0.110	0.56
P		0.20	0.007	0.02	0.005	0.009	0.01
Palm kernel %							Total
0	18	3.31	3.73^{b}	4.06^{b}	3.99^{b}	3.91^{b}	19.0^{b}
20	18	3.19	3.58^{ba}	3.53^{ab}	3.57^{ab}	3.54^{ab}	17.4^{ab}
40	18	3.12	3.58^{ba}	3.49^{ab}	3.30^{a}	3.74^{ab}	17.2^{ab}
60	18	2.88	3.23^{a}	3.24^{a}	3.05^{a}	3.33^{a}	15.7^{a}
SEM		0.102	0.101	0.169	0.147	0.121	0.43
P		0.08	0.04	0.05	0.01	0.05	0.02

Different subscripts within the same column within the copra or palm kernel groups indicate significant difference at the 5% level

when whole-milk is being fed. In the current study, feeding of 16% protein feeds had no effect on growth rate over the first three weeks. However, between three and six weeks of age, calves fed the 20% protein pellets ate more and grew faster. The calf pellets in the present study were commercially formulated and information regarding the ingredients was unavailable, so we do not know whether the rations differed in palatability or other components. The source of protein in these diets was unknown and protein type is known to affect feed intake (Kertz et al. 2017) and calf performance (Khan et al. 2016). Thus, we do not know whether the effect observed here was due simply to better palatability leading to higher feed intakes or to the protein content *per se*. However, without further research, it does suggest that specialist bull-calf rearers using a restricted milk and early weaning system should feed 20% protein meals before weaning in order to reach the liveweight targets to enable bull calf sale at 100 kg at 12 weeks of age. Achieving target weights as early as possible is important in a New Zealand context as weaned calves become available in late spring and there is pressure for finishers to obtain calves before the onset of summer and deteriorating feed quality. Feeding a low-protein meal might achieve some modest savings but these are likely to be small when compared to the price drops that can occur within days when calf sales are delayed.

Low feed intakes of commercially purchased calf pellets led us to develop and test our own customized formulation in a small pilot trial. Differences in absolute average feed intake were relatively large (29.3 vs 14.8 kg/head) but were not significant due to the large variation between pens. Under a restricted-milk system, weaning is not recommended until the calves have put on 20 kg of live weight, at which point they are consuming around 1 kg of concentrate per head per day (Muir et al. 2002). In this study, the intake of the customised ration was over 1 kg/day at the end of week 5 meaning weaning off milk could have started. On the other hand, calves on the commercial meal were still only consuming 0.82 kg/head/day at the end of week 6, resulting in delayed weaning and leading to increased milk and labour costs. Although the comparison is across years, calves fed the customised ration had similar feed intakes to those in seven previous experiments (Figure 1) whilst the feed intakes on the commercial ration were dramatically lower and similar to the pellet intakes observed in the same commercial pellets in the previous year (2007). The reason for this is unknown. Commercial diets are based on least cost formulations and in NZ there is no requirement to list the amounts of the component ingredients. Whilst the overall specifications may remain constant the ingredients or proportions may vary and this may change palatability (Miller-Cushon et al. 2013, Tere et al. 2016).

In Experiment 3, the effect of diet form was examined. Typically, calves are fed a pelleted ration which has been hammer milled and then pelletized under pressure. The pelleting process typically adds a cost of approximately $60/Tonne. In this study there was no effect of the form of the ration on intake or live weight, so the more expensive pelleting process does not appear necessary for calf performance. However, pelleting could have advantages for other purposes, e.g., retaining freshness, ease of bulk storage or facilitating ease of feeding. Bach et al. (2007) also compared pelleted *vs* non-pelleted rations and found no effect on liveweight gain. Moreover, feeding a roller-milled loose meal has the added advantage of providing the purchaser a good insight as to the ingredients of the meal they are purchasing, which is otherwise hidden by the hammer milling and pelleting process.

Internationally, soyabean meal is seen as having a high palatability (Miller-Cushon et al. 2014) and is generally regarded as the optimum protein source for solid feeds to be fed to calves (Davis & Drackley 1998; Hill et al. 2005). Comparative studies have shown that both canola meal

(Fiems et al. 1985) and cottonseed meal (Fiems et al. 1986) led to poorer calf performance than when soyabean meal was used as a protein source. All soyabean meal used in New Zealand is imported and, thus, tends to be one of the more expensive protein sources. On the other hand, palm kernel and, to a lesser extent, copra meal are imported in large quantities. In 2009, 1755 tonne of copra meal and 665,000 tonne of palm kernel was used in a range of compound feeds (New Zealand Feed Manufactures Association). It seems reasonable to assume that these lower-cost protein sources may have been incorporated into calf meals. The older calves in this study only rejected the palm kernel and copra meal when they became a significant proportion of the diet. It is worth noting that younger calves or calves that are only just starting to eat concentrates are likely to be even more sensitive to these alternative (cheaper) protein sources and to find them less palatable.

This research has demonstrated that the protein content of the concentrate ration fed to calves can influence growth rate and that some additives at high rates can affect palatability. It is the opinion of the authors that more appropriate labelling of concentrate feeds would assist calf rearers in making better-informed purchasing decisions that would help support their calf-rearing businesses.

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References

Bach A, Gimenez A, Juaristi JL, Ahedo J 2007. Physical form of a starter for dairy replacement calves on feed intake and performance. Journal of Dairy Science 90: 3028-3033.

Davis CL, Drackley JK 1998. The development, nutrition and management of the young calf. Iowa, Iowa State University Press.

Fiems LO, Bouchque CV, Cottyn BG, Bysse FX 1985. Evaluation of rapeseed meal with low and high glucosinolates as a protein source in calf starters. Livestock Production Science 12: 131-143.

Fiems LO, Bouchque CV, Cottyn BG, Bysee FX 1986. Cottonseed meal and maize gluten fed versus soyabean meal as protein supplements in calf starters. Archives of Animal Nutrition 36: 731-740.

Groenendijk ME, Lowe K, Molenaar AJ, McCoard SA, Luo D, Khan MA 2018. Growth performance of crossbred dairy calves fed different milk allowances using an automatic feeding system. New Zealand Journal of Animal Science and Production 78: 21-25.

Heinrichs AJ, Lesmeister KE 2007. Rumen development in the dairy calf. In: Calf and heifer rearing. Garnsworthy PC ed. Nottingham University Press.

Heinrichs AJ 2005. Rumen development in the dairy calf. Advances in Dairy Technology 17:179-87.

Hill TM, Aldrich JM, Schlotterbeck RL 2005. Nutrient sources for solid feeds and factors affecting their intake by calves. In-Calf and heifer rearing. Garnsworthy PC ed. Nottingham University Press.

Kertz AF, Hill TM, Quigley III JD, Heinrichs AJ, Linn JG, Drackley JK,. 2017. A 100-year review: Calf nutrition and management. Journal of Dairy Science 100: 10151-10172

Khan MA, Bach A, Weary DM, von Keyserlink MAG 2016. Invited review. Transitioning from milk to solid feed in dairy heifers. Journal of Dairy Science 99: 885-902.

Miller-Cushon EK, Montoro C, Bach A, DeVries TJ. 2013. Effect of early exposure to mixed rations differing in forage particle size on feed sorting of dairy calves. Journal of Dairy Science 96: 3257-3264

Miller-Cushon EK, Terre M, DeVries TJ, Bach A 2014. The effect of protein source on dietary selection in dairy calves. Journal of Dairy Science 97: 4444-4454.

Mirzaei M, Khorvash M, Ghorbani GR, Kazemi-Bonchenai M, Riasi A, Soltani A, Moshiri B, Ghaffari MH. 2016. Interactions between the physical form of starter (mashed vs textured) and corn silage provision on performance, rumen fermentation and structural growth of Holstein calves. Journal of Animal Science 94: 678-686.

Moran J 2002. Calf rearing. A practical guide. Landlinks Press.

Muir PD, Fugle CJ, Ormond AWA 2002. Calf rearing using a once-a-day milk feeding system: current best practice. Proceedings of the New Zealand Grasslands Association 64: 21-24.

NZ Feed Manufacturers Association www.nzfma.org.nz

Thomson BC, Muir PD, Ward KR 2018. Calf-rearing systems on dairy farms and specialist calf rearing units: results of a New Zealand survey. New Zealand Journal of Animal Science and Production 78: 173-176.

Van Amburgh MV, Drackley J 2005. Current perspectives on the energy and protein requirements of the pre-weaned calf. In Calf and heifer rearing. Garnsworthy PC ed. Nottingham University Press.