

Comparison of the Digestibility of Grain and Forage by Sheep, Red and Fallow Deer

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ABSTRACT : Two experiments were conducted to compare digestibility of 12 diets in sheep, red and fallow deer. No differences ($p > 0.05$) between sheep, red and fallow deer in digestibility of dry matter, organic matter and digestible energy content for all diets were found except for the sorghum diet and medic hay. Sheep and fallow deer digested the sorghum diet better than red deer. An *in vitro* study showed that sheep had a lower *in vitro* dry matter digestibility and digestible energy content than both red and fallow deer, with a significant interaction between animal species and feed ingredient. Deer digested straws and hays better ($p < 0.05$) than sheep. *In vitro* digestibility was lower ($p < 0.05$) than *in vivo* digestibility, but significantly correlated with *in vivo* digestibility for red and fallow deer. The *in vitro* method for digestibility estimation has potential as a rapid feed evaluation system for deer, but needs further validation. (*Asian-Aust. J. Anim. Sci.* 2002. Vol 15, No. 6 : 800-805)

Key Words : *In Vitro* Digestibility, Energy, Pasture, Grain

INTRODUCTION

The Mediterranean environment in Australia is characterised by wet, cold winters and hot, dry summers. Seasonal herbage availability for grazing deer under this environment is characterised by a low quantity of herbage in early winter, and a poor quality and quantity of herbage in summer and autumn. Variation in the feed availability limits the potential of the fallow weaner deer to reach the market body weight (45-50 kg for males; 36-38 kg for females) by 12 months of age (Mulley and Falepau, 1997). Thus supplementary feeding is a common strategy used to improve the growth of weaners during summer, autumn and early winter.

To enable deer producers to use their feed resources more efficiently, it is essential to know the nutritive value of feed ingredients for the least cost diets to be formulated, especially for common feed resources used in Australia. Currently most Australian deer farmers are using nutritive value determined in sheep as guidelines. The application of nutritive values of feeds determined by sheep for red deer feeding is questionable given red deer digest fibre better than sheep in summer (Francoise Domingue et al., 1991) and *in vitro* dry matter digestibility of some feed ingredients is higher in rusa deer compared to sheep (Latupeirissa and Dryden, 1998). The interaction between animal species and pasture species in digestibility was also reported by Milne et al. (1978). More importantly, it is well known that the determination of nutritive value of feed using deer is expensive and time-consuming due to the difficulty of

handling deer. The establishment and validation of a rapid *in vitro* assay for digestibility estimation is required by the industry although these *in vitro* methods are available for other ruminants (sheep and cattle). The objectives of this study were to compare the *in vivo* and *in vitro* digestibility between these three species and to explore the potential of using an *in vitro* method to evaluate feed for deer.

MATERIALS AND METHODS

In vivo experiment

Animals : Six fallow and 6 red deer (castrated male weaners), 8 months of age, were obtained from a commercial deer farm in South Australia. The average body weight was 28 kg (SD=1.51) for fallow deer and 64 kg (SD=1.79) for red deer. The deer were housed as a group in a 7 m × 7 m compound constructed in the middle of an animal house, with 1,900 mm ring-lock fence strained 100 mm off the floor giving a 2 m high fence, in the Animal Research Centre at Roseworthy Campus located 60 km north of Adelaide in South Australia.

After 2 months of training the deer to hand-feed using fresh lucerne and grains, the deer were transferred into individual stalls. The dimensions of the stalls were 1,200 mm long × 1,950 mm high × 900 mm wide for fallow deer and 1,800 mm long and 1,950 mm high × 1,200 mm wide for red deer. Holes with a diameter of 100 mm were cut in the stalls to allow deer to view each other in the next stall to reduce fretting and fractious behaviour. The feeder was fixed on the door next to a 5 L water bucket. To reduce the stress on deer associated with fitting and using collection bags, a faecal collection net was placed underneath each individual

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stall, similar to the faeces collector used in metabolic cages for sheep.

Six Merino wethers, 12 months of age, were sourced from Farm Services, Adelaide University, Roseworthy and housed in individual pens. The average body weight for sheep was 62 kg (SD=1.51). Sheep were fed lucerne chaff for 3 weeks while acclimatising to the animal house environment. Three days before the commencement of the experiment, all sheep were fitted with faecal collection bags.

Experimental diets : The *in vivo* experiment was conducted over two periods. In each period, 6 diets (table 1) were tested using a 6×6 Latin Square design. Feed ingredients evaluated included grains (barley, wheat, sorghum, oats and lupin), straw (barley straw and pea straw) and hays (lucerne chaff, oaten chaff, wheaten chaff and medic hay). The experimental diets were fed *ad libitum* for two weeks, followed by a week of total faecal collection. Water was available at all times. Faeces were collected daily and 10% of the total weight were sub-sampled and dried at 60°C. Hair in the faeces was removed manually. Feed residues were collected and weighed daily, and subsampled for chemical analyses.

Dry matter, ash and crude protein of feed and faeces were determined using standard methods (AOAC, 1980). Gross energy (GE) was measured using a Parr 1261 Adiabatic Bomb Calorimeter. The digestibility of individual ingredients was calculated using the following equation (Charmley and Greenhalgh, 1987);

$$a=(v-b*p)/(1-p)$$

where a is the coefficient for the unknown feed

ingredient, b is the coefficient for the ingredient with a known digestibility, v is digestibility of the diet, and p is the proportion in the diet of the ingredient with a known digestibility.

In vitro experiment

Animals and feeds : Three fallow deer, 3 red deer (male, 8-10 months old) and 3 Merino wethers were obtained from Farm Services, Adelaide University, Roseworthy Campus. All deer were held in a paddock at the Deer Farm on Roseworthy Campus, and 3 sheep were housed in the Animal House at Roseworthy Campus. Deer and sheep were fed a basic diet consisting of 50% lucerne chaff and 50% oaten chaff. During November, December and January, one sheep, 1 red and 1 fallow deer were slaughtered and the rumen fluid collected for *in vitro* digestibility estimation. CO₂ was passed through the rumen fluid to maintain anaerobic conditions and the container was sealed and kept in the water bath at 39°C before adding to the incubation tubes. The time from collection to completion of the inoculation process was less than 2 h as recommended by Schwartz and Nagy (1972). All feed samples tested in the *in vivo* experiment were milled through a 1 mm screen.

In vitro measurement : The *in vitro* dry matter digestibility (DMD) and digestible energy (DE) content was determined using the Tilley-Terry method (Tilley and Terry, 1963). In brief, a sample of the feed (0.5 g) was weighed into incubating tubes and 10 mL of rumen fluid and 40 ml of buffer (pH=5.8) were added. Tubes were flushed with CO₂ and capped immediately. Ten replicates of each sample were incubated in a shaking water bath at 39°C for 48 h. After the samples were centrifuged at 3,000 rpm for 15 min. and

Table 1. Experimental diet composition for *in vivo* study in animal house (g)

Diet no.	Ingredient	Period 1			Diet no.	Ingredient	Period 2		
		Fallow	Red	Sheep			Fallow	Red	Sheep
1	Lucerne hay	1,000	1,800	1,600	7	Lucerne hay	1,400	2,200	1,600
	Mineral	10	10	10		Mineral	10	10	10
2	Lucerne hay	300	540	480	8	Lucerne hay	1,120	1,760	1,280
	Wheaten hay	700	1260	1120		Barley grain	280	440	320
3	Mineral	10	10	10	9	Mineral	10	10	10
	Lucerne hay	300	540	480		Lucerne hay	1,120	1,760	1,280
4	Oaten hay	700	1,260	1,120	10	Wheat grain	280	440	320
	Mineral	10	10	10		Mineral	10	10	10
5	Medic hay	1000	1,800	1,600	11	Lucerne hay	1,120	1,760	1,280
	Mineral	10	10	10		Oat grain	280	440	320
6	Lucerne hay	400	700	600	12	Mineral	10	10	10
	Barley straw	400	700	600		Oaten hay	1,120	1,760	1,280
7	Mineral	10	10	10	11	Lupin	280	440	320
	Lucerne hay	400	700	600		Mineral	10	10	10
8	Pea straw	400	700	600	12	Lucerne hay	1,120	1,760	1,280
	Mineral	10	10	10		Sorghum grain	280	440	320
9	Lucerne hay	400	700	600	12	Mineral	10	10	10
	Mineral	10	10	10		Mineral	10	10	10

washed with distilled water, 50 mL of pepsin solution was added to each tube and incubated for another 48 h at 39°C. After incubation, the samples were centrifuged (3,000 rpm) and the residues dried at 60°C over night. Dry matter and gross energy in the residue were determined using the standard procedure (AOAC, 1980). In each batch, a quality control lucerne sample of known *in vivo* digestibility and DE content was included to correct the *in vitro* measurement.

Statistics

The *in vivo* experiment was a Latin square design. Main effects (diet, animal species and interaction) were analysed using a general linear model from Systat software (Wilkinson et al., 1996). Data from the *in vitro* experiment was analysed using ANOVA to compare the difference between animal species for each feed ingredient. The relationship between *in vitro* and *in vivo* measurements was tested using the regression procedure in Systat.

RESULTS

There were no differences ($p>0.05$) between sheep, red and fallow deer in digestibility of dry matter, organic matter and DE content for all diets except for the sorghum diet and medic hay (table 2). Sheep and fallow deer had a higher digestibility ($p<0.05$) for the sorghum diet than red deer. Sheep had a higher digestibility ($p<0.05$) of crude protein than deer for medic hay.

Overall, sheep had a lower *in vitro* DMD (52%) and DE (9.5 MJ/kg) than both red and fallow deer, with average values for deer being 60% and 10.5 MJ/kg, respectively. However, there was significant interaction between animal

species and feed ingredient (table 3). In particular, there were no differences ($p>0.05$) in *in vitro* DMD and DE of lucerne chaff and medic hay between sheep, red and fallow deer, but deer digested straws and hays better than sheep ($p<0.05$). Sheep had a lower *in vitro* DMD and DE of barley, sorghum and wheat grains. The DE content of lupin was higher ($p<0.001$) for sheep than deer.

There were significant differences ($p<0.05$) between *in vivo* and *in vitro* DMD or DE content (table 4). The magnitude of the difference was higher for sheep than deer. For example, *in vivo* DMD was 10-12% units higher than *in vitro* DMD for deer and 19% units higher for sheep for all feed ingredients tested, with a similar trend for DE. The difference between *in vivo* and *in vitro* values were more obvious for grain samples than straw or hay samples (table 4).

The simple regression analysis showed that *in vitro* DMD and DE content were correlated ($R^2>0.5$) with the *in vivo* DMD and DE, respectively, for both red and fallow deer when the data for all ingredients or hays/straws were pooled for analysis. However, the correlations between these parameters were poor for sheep (table 5). When data for straw and hay samples were analysed, the correlation between *in vivo* and *in vitro* DMD or DE were not significant ($p>0.05$) for fallow deer, but significant ($p<0.05$) for sheep.

DISCUSSION

In vivo digestibility

The outcome of the *in vivo* experiment confirms the difference in digestion between sheep and deer. However,

Table 2. Nutrient digestibility of the diets by sheep (12 month old wethers), red and fallow deer (8 month old weaners) measured using total faecal collection

Diet no.	Dry matter (%)			SEM	P value	Crude protein (%)			SEM	P value	Digestible energy (MJ/kg air dry)			SEM	P value
	Fallow	Red	Sheep			Fallow	Red	Sheep			Fallow	Red	Sheep		
<i>Period 1</i>															
1	64.3	65.8	64.0	1.09	0.470	74.7	74.7	76.1	0.88	0.429	10.2	10.3	10.1	0.18	0.610
2	58.2	59.5	59.8	0.89	0.516	67.7	67.4	68.4	0.83	0.666	9.4	9.6	9.5	0.15	0.777
3	60.7	62.1	63.3	1.22	0.355	64.4	64.6	67.5	1.52	0.298	9.9	10.0	10.2	0.20	0.663
4	60.1	61.3	62.9	1.07	0.221	67.9 ^b	68.7 ^b	71.4 ^a	0.76	0.012	9.4	9.6	9.8	0.17	0.230
5	58.8	60.7	58.8	1.08	0.355	69.5	67.2	68.5	0.92	0.230	9.1	9.3	9.0	0.19	0.439
6	55.6	60.1	57.5	1.22	0.065	66.0	67.5	68.9	1.11	0.216	8.8	9.4	9.2	0.18	0.073
<i>Period 2</i>															
7	66.4	63.9	62.8	1.89	0.399	77.1	73.9	74.2	1.39	0.217	10.5	10.0	9.9	0.32	0.391
8	65.0	68.2	68.8	1.79	0.335	73.8	74.1	75.9	2.03	0.739	10.3	10.8	11.0	0.32	0.325
9	69.3	70.9	69.7	1.28	0.688	77.7	76.1	76.4	1.35	0.687	11.0	11.3	11.1	0.23	0.698
10	68.1	69.5	70.2	1.64	0.689	79.3	76.4	79.3	1.52	0.332	11.2	11.3	11.5	0.30	0.752
11	57.7	62.5	55.2	2.64	0.175	52.8	64.7	60.0	3.23	0.050	10.1	10.6	9.4	0.47	0.225
12	74.2 ^a	70.8 ^b	76.0 ^a	1.16	0.018	79.9 ^a	74.5 ^b	80.5 ^a	1.08	0.002	11.9 ^a	11.2 ^b	12.3 ^a	0.21	0.009

Values followed with different letters in rows within each chemical component are different between animal species at $p=0.05$; SEM=standard error of means.

Table 3. Dry matter digestibility and digestible energy content in feed ingredients for sheep, red and fallow deer measured using an *in vitro* method (data were corrected using the *in vivo* data for Lucerne chaff)

Ingredient	Dry matter digestibility (%)				P-value	Digestible energy content(MJ/kg air dry)				P-value
	Fallow	Red	Sheep	SEM		Fallow	Red	Sheep	SEM	
Forages										
Barley straw	40.0 ^a	35.2 ^b	31.3 ^c	0.56	0.001	6.6 ^a	5.6 ^b	4.7 ^c	0.12	0.001
Lucerne	64.5	65.4	64.0	0.64	0.278	10.3	10.2	10.1	0.13	0.486
Medic hay	58.7	58.5	59.6	0.79	0.549	9.4	9.2	9.6	0.16	0.099
Oaten hay	47.5 ^{ab}	50.0 ^b	45.2 ^a	1.07	0.005	8.2 ^a	8.5 ^a	7.7 ^b	0.18	0.017
Pea straw	44.0 ^a	48.6 ^a	37.7 ^b	1.59	0.001	7.3 ^a	8.2 ^a	5.9 ^b	0.19	0.001
Wheaten hay	42.8 ^a	42.4 ^a	38.1 ^b	0.96	0.001	7.7 ^a	7.5 ^a	6.5 ^b	0.18	0.000
Grains										
Barley	72.0 ^a	71.5 ^a	55.6 ^b	0.77	0.000	12.2 ^a	12.4 ^a	10.0 ^b	0.16	0.000
Lupins	74.2 ^a	76.3 ^b	75.4 ^{ab}	0.64	0.107	14.0 ^a	14.4 ^b	15.5 ^c	0.11	0.000
Oats	65.3 ^a	56.6 ^b	50.3 ^c	0.86	0.000	11.8 ^a	10.2 ^b	10.0 ^b	0.20	0.001
Sorghum	60.1 ^a	61.6 ^a	46.7 ^b	1.00	0.003	10.8 ^a	11.2 ^a	8.7 ^b	0.21	0.001
Wheat	70.3 ^a	67.2 ^b	54.5 ^c	0.91	0.001	12.0 ^a	11.7 ^a	10.0 ^b	0.18	0.001

Values followed with different letters in rows for each ingredient are different between animal species at $p=0.05$ for dry matter digestibility or digestible energy content; s.e.m.=standard error of means.

Table 4. Comparison of *in vivo* and *in vitro* dry matter digestibility (DMD) and digestible energy (DE) content of grains, hays and straws for sheep, red and fallow deer

Method	DMD (%)			DE (MJ/kg air dry)		
	Fallow	Red	Sheep	Fallow	Red	Sheep
All ingredients						
<i>In vivo</i>	68.4	70.4	70.2	11.3	11.6	11.6
<i>In vitro</i>	58.1	57.6	50.8	10.0	9.9	9.0
<i>T test</i>	3.335	4.038	3.845	2.873	3.634	3.229
<i>P value</i>	0.008	0.002	0.003	0.017	0.005	0.009
Hays/straws						
<i>In vivo</i>	56.0	58.0	58.1	9.0	9.3	9.3
<i>In vitro</i>	49.6	50.0	46.0	8.2	8.2	7.4
<i>T test</i>	2.561	2.571	3.335	2.103	2.668	3.287
<i>P value</i>	0.050	0.050	0.021	0.089	0.044	0.022
Grains						
<i>In vivo</i>	83.3	85.2	84.7	14.1	14.3	14.4
<i>In vitro</i>	68.4	66.6	56.5	12.2	12.0	10.8
<i>T test</i>	2.596	3.667	3.058	2.237	2.824	2.127
<i>P value</i>	0.060	0.021	0.038	0.089	0.048	0.101

the interaction between animal species and feed ingredient make it difficult to generalise the digestion capability of sheep and deer, suggesting that the digestibility data for sheep cannot be applied to deer for all ingredients. Such interactions have also been reported by other researchers. For example, Palmer and Cowan (1979) found no difference between sheep and white-tailed deer in the digestibility of protein, fibre and energy although the DMD

Table 5. Correlations for *in vitro* and *in vivo* dry matter digestibility (DMD, %) and digestible energy (DE, MJ/kg air dry) content of feed ingredients for red and fallow deer

Method	DMD			DE		
	Fallow	Red	Sheep	Fallow	Red	Sheep
All ingredients						
Constant	12.990	20.953	49.843	1.251	2.569	6.590
Coefficient	0.953	0.859	0.401	1.004	0.910	0.557
R^2	0.579	0.521	0.107	0.725	0.690	0.316
<i>T test</i>	3.515	3.126	1.034	4.866	4.473	2.039
<i>P value</i>	0.007	0.012	0.326	0.001	0.002	0.072
<i>n</i>	11	11	11	11	11	11
Hays/straws						
Constant	30.250	38.811	40.876	3.909	5.786	6.230
Coefficient	0.519	0.381	0.374	0.619	0.428	0.411
R^2	0.625	0.555	0.670	0.587	0.675	0.698
<i>T test</i>	2.582	2.233	2.849	2.386	2.884	3.038
<i>P value</i>	0.061	0.089	0.046	0.076	0.045	0.038
<i>n</i>	6	6	6	6	6	6

was higher for sheep than deer fed on lucerne chaff. Likewise Milne et al. (1976, 1978) reported sheep digested the *Agrostis-Festuca spp.* better than red deer, while red deer digested the *Calluna vulgaris* better than sheep. These differences in digestibility between sheep and deer can be explained by a number of factors including rate of passage of digesta, structure of the digestive tract, chemical composition of feed and recycling of urea.

Most researchers believe the lower digestibility in feed by red deer is due to the faster rate of hay passage through the digestive tract of deer compared with sheep (Grimes, 1968; Palmer and Cowan, 1979; Milne et al., 1976), but other dietary factors and the difference in the structure of digestion tract may also contribute to the interaction observed between animal species and feed ingredient. For instance, Francoise Domingue et al. (1991) and Fennessy et al. (1980) found deer can digest fibre, especially lignin, better than sheep. Milne et al. (1978) showed red deer had a high digestibility on pasture with a high lignin content (19–21% on DM basis) in comparison with low lignin pasture (4.4% on DM basis), probably due to the rapid fermentation and brief retention of digesta of deer associated with deer having a shorter small intestine than sheep. The large caecocolon of deer may also contribute significantly to the improved fibre digestion, but the rumen capacity in comparison with colon is relatively low for deer than sheep, with a colon:rumen capacity of 1:14–15 for red and fallow deer and 1:27–30 for sheep (Hofmann, 1985). This suggests deer might digest feed better than sheep, depending on the fibre content of the pasture and the quality of feed ingested by deer. Under grazing condition, the better conversion of pastures may also be associated with a higher quality of pasture ingested by deer which are more selective graziers than sheep.

The high digestibility of crude protein by sheep fed medics is difficult to explain. However, it has been confirmed that white-tailed deer can recycle more urea than sheep or cattle and the recycled urea in the lower digestive tract cannot be completely reabsorbed, resulting in a higher metabolic faecal nitrogen estimate (Robbins et al., 1974). It is not clear whether the low protein digestibility of deer is associated with the formation of tannin-protein complexes known to increase the nitrogen excretion through faeces (Nishimuta et al., 1973).

The similar digestibility of red and fallow deer was expected given their similar fermentation capability. Red and fallow deer have a similar ratio of small and large intestines, colon and rumen capacity (Hofmann, 1985), and there is no difference in weight ratios of different stomach compartments relative to live weight between red and fallow deer (Nagy and Regelin, 1975)

***In vitro* digestibility**

Sheep had the lowest digestibility of *in vitro* DMD and DE for all straws and hays except for legume pastures. This is not surprising as the *in vivo* studies indicate that deer can digest fibre, especially lignin, better than sheep (Francoise Domingue et al., 1991; Fennessy et al., 1980). While some of the difference in *in vivo* digestibility result from the difference in the structure of digestive tract, the *in vitro* results can only be attributed to the bacterial activity as the

feed samples were incubated under the same conditions and the same diet was fed to animals before the rumen fluid was sampled. This experiment suggests the *in vitro* data from sheep might not be a reliable indicator for deer and an *in vitro* system for deer is required to develop a rapid feed evaluation system.

The *in vitro* DMD and DE were lower than *in vivo* values, but the *in vitro* and *in vivo* data for overall values was significant correlated as found in sheep (Miao et al., 1991). The high *in vivo* digestibility is often expected because the digestion is a function of physical and biochemical activities involved in mastication, rumination and contraction of digestion tract and the influence of multiple enzymes in the digestion tract. However, the *in vitro* system used in the current experiment only involves a single enzyme (pepsin) although the incubation tubes were shaken continuously.

Other factors contributing to the lower *in vitro* digestibility includes buffer pH, the type of basic diets fed to animals for supplying rumen fluid, and the quality of feed samples for testing. Burbank et al. (1979) found that the *in vitro* digestibility was lower in the system buffered at pH 5.6, compared to pH 7.0. The pH of rumen flora of deer (white-tailed deer) can vary from 5.1 to 6.5 depending on the type of pastures, seasons and the individual deer. The variation in pH of rumen fluid and the extent of the fermentation of the samples governed by the chemical composition of the feed, especially carbohydrate make it difficult to incubate the sample at an optimum pH throughout the process.

The type of basic diet can also influence the *in vitro* digestibility measurement through changing pH of rumen fluid. For example, Robbins et al. (1975) reported that the *in vitro* DMD was close to the *in vivo* value for alfalfa and commercial rations when using the inocula from deer fed on lucerne. However, if the inocula was sampled from deer fed a commercial diet, the *in vitro* digestibility was lower than the *in vivo* value for commercial diet. Thus McCullough, (1979) suggested ideally the basic diet should be similar to the test diet. To meet this ideal situation, the animals have to be fed a diet based on the test feed for a period before sampling rumen fluid. This is not practical as the objective of the *in vitro* system is to estimate nutritive value of feed rapidly. More importantly a large number of samples can be tested in a single batch, which means that the pH is optimised for some samples, but not others.

The quality of pastures might contribute to the low digestibility of straws and hays. The results of this study showed the *in vitro* digestibility of lucerne and medics is higher than other samples and similar to the *in vivo* data without significant difference between animal species, probably due to the high protein content and/or carbohydrates in legume pastures. McCullough (1979)

demonstrated that addition of urea and/or starch increased the *in vitro* dry matter digestibility, with the effect being dependent on the quality of the herbage tested.

Relationship between *in vivo* and *in vitro* digestibility

The relationship between *in vitro* and *in vivo* data for deer indicates a potential of predicting feed digestibility using a rapid and inexpensive *in vitro* system. To develop a commercial service for the deer industry, it is recommended more samples be analysed and incorporated into the system to further validate the *in vitro* system which would allow deer farmers to adjust their feeding strategy quickly to meet the nutrient requirements for grazing deer. Because of the difficulty of maintaining deer with rumen fistula, the development of calibrations for near infra-red spectrophotometer (NIR) for the prediction of nutritive value of feed (an approach used for sheep and cattle industries) would be an ideal option.

In conclusion, there are differences in the *in vivo* digestibility between sheep and deer, depending on the type of feed ingredients. The *in vitro* system shows some potential for developing a rapid feed evaluation service for the deer industry. However, more samples need to be tested to validate the system. Due to the difficulty of deer handling, an NIR calibration, which is used commercially in the sheep and cattle industries, may be an ideal option in the future.

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