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Intra-ruminal particle size reduction in deer fed fresh perennial ryegrass (*Lolium perenne*) or chicory (*Cichorium intybus*)

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SUMMARY

Pure swards of chicory (*Cichorium intybus*) and perennial ryegrass (*Lolium perenne*) were grown at Palmerston North, New Zealand. They were cut daily and fed fresh at 2 kg dry matter (DM)/day to ten hand-reared rumen fistulated castrated red deer stags kept in metabolism crates in April and October 1994. The efficiency of particle breakdown during the time allowed for rumination (⟨C.PART⟩) to below the critical size required to leave the rumen (passage through a 1 mm sieve) and jaw activities (i.e. eating and ruminating) were measured. Total eating time and the number of eating bouts were similar for deer fed each forage, but deer fed chicory had a greater chewing rate during eating (97·4 *v.* 81·0 chews/min), and a higher number of chews/g DM eaten (36·2 *v.* 31·5). Deer fed chicory had lower total ruminating time (30 *v.* 257 min/22·5 h), lower number of boli ruminated (38 *v.* 440/22·5 h), lower number of rumination bouts (5·4 *v.* 16·2/22·5 h) and less chews per minute ruminating (16·5 *v.* 44·3) than those fed perennial ryegrass. Of the ten deer used to measure (⟨C.PART⟩), only four ruminated when fed chicory compared with nine when fed perennial ryegrass.

Deer fed chicory had a higher efficiency of particle breakdown (⟨C.PART⟩: 0·64 *v.* 0·42), higher fractional degradation of particles > 1 mm (9·2 *v.* 5·1%/h) and faster fractional disappearance of total DM from the rumen (10·2 *v.* 5·3%/h). All three measurements for chicory were similar in deer that did or did not ruminate, but with perennial ryegrass, all values were considerably reduced in the deer that did not ruminate.

It was concluded that chicory can be broken down faster in the rumen, with less rumination being required than for perennial ryegrass, and that some deer (60%) could break down swallowed chicory to below the critical particle size without ruminating at all. The faster clearance of DM from the rumen explains the high voluntary feed intake (VFI) of deer grazing chicory. Future research needs to be done to partition rumen fractional disappearance rate into its components, rumen fractional degradation rate and rumen fractional outflow rate in deer fed chicory and perennial ryegrass.

INTRODUCTION

Chewing during eating and chewing during rumination are the two principal processes which reduce ingesta particle size and therefore affect the clearance of digesta from the rumen in animals fed grass and legumes (Ulyatt *et al.* 1986). The first process appears to be very efficient in damaging surfaces, releasing soluble materials from feed and forming feed into boli (Poppi *et al.* 1981; Ulyatt 1984). The function of rumination is to further reduce the particle size of rumen contents until the critical size is reached which allows a high probability of leaving the rumen (Ulyatt *et al.* 1986). For deer, the critical particle size has been defined as a passage through a 1 mm sieve (Domingue *et al.* 1991*a*). Faster particle breakdown as affected by more efficient chewing during eating and during ruminating may lead to the more rapid clearance of digesta from the rumen and hence to increases in VFI (Ulyatt *et al.* 1986).

Young deer grazing chicory (*Cichorium intybus*) have been shown to have a greater liveweight gain (LWG) and VFI compared to those grazing perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture (Niezen *et al.* 1993; Kusmartono *et al.* 1996). Behaviour observations, during both indoor

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feeding (Hoskin *et al.* 1995) and grazing (Kusmartono *et al.* 1996) showed that deer fed chicory spent a similar time eating, but considerably less time ruminating compared to those fed perennial ryegrass-based pasture. Dryden *et al.* (1995) showed that the efficiency of chewing during eating by deer in reducing particle size to < 1 mm (⟨C.EAT⟩) was less for chicory (0·27) than for perennial ryegrass (0·37) or the legumes *Lotus corniculatus* and lucerne (0·50). The objective of this study was to investigate the efficiency of particle breakdown (⟨C.PART⟩) during the time allowed for rumination in deer fed chicory and perennial ryegrass.

MATERIALS AND METHODS

Experimental design

An indoor experiment was conducted using rumen fistulated red deer (*Cervus elaphus*) fed either perennial ryegrass (*Lolium perenne* cv. Nui) or chicory (*Cichorium intybus* cv. Puna). The experiment was conducted at Massey University Deer Research Unit in 1994 and was divided into period 1 (P1; April 1994) and period 2 (P2; October 1994). The five deer fed chicory in P1 were fed perennial ryegrass in P2, whilst those fed perennial ryegrass in P1 were fed chicory in P2. Each period was divided into an adjustment (10 days) and rumen contents baling and jaw recording (5 days) sub-periods. Parameters recorded included eating, ruminating, rumen pool size and the particle size distribution of rumen contents.

Forages

The chicory was sown in January 1993 and was a pure, vegetative crop. The perennial ryegrass was sown in 1991, and was from a pure sward, *c.* 10 cm in height. Potassic superphosphate (9% P; 10% S and 7% K) was applied at 250 kg/ha, corresponding to 22·5 kg P/ha, onto perennial ryegrass and chicory in late autumn (April) 1993 and 1994. Also, four urea applications each of 37 kg N/ha were made to each forage in early spring (August 1993), late spring (October 1993), late summer (February 1994) and spring (August 1994), respectively. Fresh forage was cut daily at 15.00 h using a mower; half was fed immediately after cutting and the remainder was spread on a concrete floor indoors overnight in a cool building to prevent deterioration.

Animals, housing and diets

Ten castrated, hand-reared stags each fitted with an 83 mm diameter rumen cannula were used. Mean initial and final liveweights (±S.D.) of the animals were 145 (±11·6) and 135 (±10·7) kg for P1 respectively, and 129 (±12·6) and 127 (±13·2) kg for P2 respectively. The animals were individually housed in specially constructed deer metabolism crates (Milne *et al.* 1978), to which they were well accustomed. One side of each cage was movable and could be used to adjust the floor area.

The animals were randomly allocated to the two diet treatments based on liveweight, so that each treatment group contained five animals with equal mean liveweight. Prior to being brought into cages, the animals were grazed on either perennial ryegrass or chicory for 4–5 days. In the cages, a 10-day adjustment period allowed animals to adjust to indoor conditions, to the two diets offered and to the handling procedures, including restriction of movement caused by reducing the floor area. Rumen contents baling and jaw recording was done during days 11–15. Jaw harnesses were fitted to each animal 4 days before jaw movement recording commenced, to allow the animals to become accustomed to them.

During the adjustment and rumen contents baling and jaw recording periods, all animals were fed at 08.30 and 15.30 h at 2 kg DM/day. The amount of fresh material fed was based on dry matter (DM) percentage determined on the previous day. The actual dry matter intake (DMI) was calculated by taking triplicate samples of feed offered daily at 15.00 and 08.00 h the following morning for DM determination (100 °C; 18 h). During the experiment, animals had free access to water and mineralized salt blocks (Dominion Salt, Blenheim, NZ). Duplicate 200 g samples of the feed offered were taken daily, pooled and kept at −20 °C, and subsamples were subsequently taken for chemical analysis.

Measurement of efficiency of particle breakdown

Jaw activities, such as eating, ruminating and resting were recorded using the method described by Stafford *et al.* (1993). During measurement of (⟨C.PART⟩), animals were allowed to consume feed from 08.30 to 11.30 h (P1) and from 08.30 to 22.00 h (P2); all feeds were then removed for 5 h (P1) and 9 h (P2) so that (⟨C.PART⟩) could be measured. The sequence was changed for P2 because some animals did not ruminate during the day in P1 (11.30–16.30 h); consequently, a longer time was allowed for rumination in P2 and this was measured during the night, when the deer were more likely to ruminate. Baling of rumen contents was done twice a day on each animal. The first (FB) and second (SB) balings were done at 11.30 and 16.30 h (P1) and at 22.00 and 07.00 h (P2). Over a 5-day period, one animal fed perennial ryegrass and one animal fed chicory were baled each day in each period, with time of rumination being recorded between the two balings. At each baling, all rumen contents were removed, weighed, mixed thoroughly and subsampled before returning the warmed rumen contents to the rumen. Subsamples of rumen digesta were taken for: (i) triplicate DM determinations, and

(ii) particle size analysis for calculation of (⟨C.PART⟩) in reducing particle size of rumen contents between the two baling times. The process of baling took 20–25 min per animal. The animals remained standing and were not tranquillized during rumen baling.

Jaw activity (i.e. rumination and idling) was recorded between the two baling times (*c.* 5 and 9 h in P1 and P2, respectively). A 4-channel chart recorder (Graphtec Linearecorder WR3701-4Hx1, Japan) connected to the jaw harnesses used in this study allowed simultaneous recording of jaw activity from each of two animals (one on perennial ryegrass; one on chicory).

In addition, jaw activity (i.e. eating, ruminating and idling) was also recorded during the 13·5 h feeding time in P2. The recording system was similar to that described by Stafford *et al.* (1992) for counting jaw activity. An individual 4-channel chart recorder (Graphtec Linear recorder WR3701-4HX1, Japan) was assigned to each animal, allowing simultaneous recording of eating, ruminating and idling from each of two animals (one perennial ryegrass; one chicory). Jaw movements were sensed as pressure changes in a partially inflated rubber bag held under the jaw by a halter. The bag was a section of bicycle inner tube, closed off at one end, the other end sealed and cemented over a flexible nylon pipe (3·5 mm i.d.) joined to an 0·8 m section of coiler rubber infusion tubing (CenVet, Australia) which accommodated animal movement. Nylon piping connected this rubber tubing to an electronic pressure transducer (Statham, ADCG, Hongkong) mounted outside the cage. The transducer was connected via a pre-amplifier to the open recorder. Time spent eating or ruminating was interpreted from the chart recorder output as described by Stafford *et al.* (1993) and Hoskin *et al.* (1995).

Laboratory methods

Prior to laboratory analysis, subsamples of the pooled feed offered were freeze-dried and ground to pass a 1 mm mesh diameter sieve (Wiley mill, USA). Organic matter (OM) content was measured by ashing in a furnace at 500 °C for 16 h and total nitrogen (N) was determined by the Kjeldahl procedure, using a selenium catalyst and sulphuric acid digestion. Hot water soluble carbohydrate (HWSC) and pectin were extracted using boiling water and ammonium oxalate respectively, and determined as described by Bailey & Ulyatt (1970). Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were determined by the detergent system of Van Soest (1994). The DM of rumen contents was determined by oven-drying (70 °C) for 3 days, until no further loss in weight occurred.

The particle size distribution of rumen contents samples was determined by wet sieving using the same apparatus (Turner & Newall Ltd, NZ) and following the procedure described by Domingue *et al.* (1991*b*). Sieve sizes (length of side of square hole) used in the present study were 2·0, 1·0, 0·5 and 0·25 mm. Materials retained on the sieves were washed onto weighed filter paper (Whatman No. 21) in a Buchner funnel, and oven-dried at 100 °C for 24 h to determine dry weight of each particle size fraction. The dry weight of material not retained on the sieves (< 0·25 mm particles) was determined by difference from the initial sample dry weight and the sum of recovered particulate DM fractions.

Calculation of data and statistical analysis

The efficiency of particle breakdown and disappearance from the rumen during the time allowed for rumination were calculated using Eqns 1–3.

$$\text{Efficiency of particle breakdown (⟨C.PART⟩)} = \frac{\text{Wt of pool DM} > 1\text{ mm at FB} - \text{Wt of pool DM} > 1\text{ mm at SB}}{\text{Wt of pool DM} > 1\text{ mm at FB}} \quad (1)$$

$$\text{Fractional degradation of particles} > 1\text{ mm (\%/h)} = \frac{(\text{DM of pool} > 1\text{ mm at FB} - \text{DM of pool} > 1\text{ mm at SB} \times 100}{\text{DM of pool} > 1\text{ mm at FB} \times \text{Hours allowed for rumination}} \quad (2)$$

$$\text{Fractional disappearance of total DM (\%/h)} = \frac{(\text{Total DM pool at FB} - \text{Total DM pool at SB}) \times 100}{\text{Total DM pool at FB} \times \text{Hours allowed for rumination}} \quad (3)$$

Table 1. *Chemical composition (g/kgDM) of perennial ryegrass and chicory*

	Period 1		Period 2	
	Perennial ryegrass ($n = 2$)	Chicory ($n = 2$)	Perennial ryegrass ($n = 2$)	Chicory ($n = 2$)
Dry matter (g/kg) ($n = 7$)	249	152	245	170
Ash	109	189	95	171
Total nitrogen	33·0	28·1	27·8	25·7
Water-soluble carbohydrate (*a*)	140	116	158	127
Pectin (*a*)	16	83	18	91
NDF	376	191	384	184
ADF	196	137	207	132
Hemicellulose (*b*)	179	54	178	52
Cellulose (*b*)	167	119	183	120
Ratio RFC:SC (*a*:*b*)	0·38	1·29	0·40	1·45
Lignin	30	18	24	12

* Readily fermentable carbohydrate:structural carbohydrate.

Data for eating and ruminating behaviour in P2 were tested for significant differences between treatment means by one-way analysis of variance using the General Linear Model (GLM) procedure (SAS 1987). Data for ⟨C.PART⟩ were analysed within each period by one-way analysis of variance, and when this showed similar results within each period, further analyses were conducted using a changeover design, combining data for both periods. When the changeover design was applied to parameters measured, using the General Linear Model (GLM) procedure (SAS 1987), between animal and between feeding sequence variation were first removed, before analysing for dietary and period effects. Least Square Means (LSM) analysis was used to test the differences between treatments.

RESULTS

Chicory contained lower DM, NDF, ADF, hemicellulose, cellulose and lignin concentrations than perennial ryegrass, but higher ash and pectin concentrations (Table 1), with these differences being apparent in each feeding period. The ratio of readily fermentable:structural carbohydrate was consistently higher for chicory.

The eating time and the number of eating bouts were similar in period 2 for deer consuming chicory and perennial ryegrass (Table 2). Deer consuming chicory had a greater chewing rate during eating ($P < 0·01$), less chews/g fresh feed eaten ($P < 0·01$) and higher number of chews/g DM eaten ($P < 0·01$) than deer fed perennial ryegrass. Relative to deer fed perennial ryegrass, deer fed chicory had lower total ruminating time, lower number of boli ruminated, lower number of rumination bouts ($P < 0·05$) and less chews per minute ruminating ($P < 0·01$). The number of chews per bolus ruminated by deer fed chicory tended to be lower ($P = 0·14$) than those fed perennial ryegrass.

A lower number of deer ruminated when fed chicory (4/10) than when fed perennial ryegrass (9/10; Table 3). Considering the total deer fed each forage, deer fed chicory had a significantly lower ruminating time (P1, $P = 0·06$; P2, $P = 0·10$), but higher efficiency of particle breakdown (⟨C.PART⟩; P1, $P < 0·05$; P2, $P = 0·11$), higher fractional degradation of particles > 1 mm (P1, $P < 0·01$; P2, ($P < 0·05$) and higher fractional disappearance of total DM from the rumen ($P < 0·01$ for both periods) compared to those fed perennial ryegrass (Table 3). Similar results for (⟨C.PART⟩), fractional degradation rate of particles > 1 mm and fractional disappearance rate were recorded in the deer that ruminated, with the differences attaining significance at $P < 0·05$ in the analysis involving both periods. Statistical tests were not possible for the deer that did not ruminate, because of the low animal numbers involved. However, it is evident that efficiency of particle breakdown (⟨C.PART⟩), fractional degradation rate and fractional disappearance rate were similar in deer fed chicory that did or did not ruminate, whereas with perennial ryegrass all three were considerably reduced in the deer that did not ruminate.

Weight of particles > 1 mm at FB tended to be higher in deer fed chicory in both periods than those fed perennial ryegrass, but the difference did not attain significance (Table 4). However, at SB the weight of particles > 1 mm in rumen contents was consistently less for deer fed chicory than those fed perennial ryegrass ($P < 0·05$). Particle size distribution

Table 2. *Eating and ruminating times of red deer fed fresh perennial ryegrass or chicory during period 2, when feed was offered for 13·5 h per day*

	Perennial ryegrass (n = 5)	Chicory (n = 5)	S.E. (D.F. = 8)
Eating behaviour			
Eating time (min/13·5 h)	221	209	49·2
Eating bouts (no/13·5 h)	8·8	11·2	1·84
Chews/minute	81·0	97·4	1·73
Chews/g fresh	6·5	4·0	0·14
Chews/g DMI	31·5	36·2	0·79
Ruminating behaviour*			
Ruminating time (min/22·5 h)	257	30	54·6
Ruminating bouts (no/22·5 h)	16·2	5·4	3·11
Ruminating boluses (no/22·5 h)	439·6	38·4	93·91
Chews/bolus ruminated	92·9	40·0	22·67
Chews/minute ruminating	44·3	16·5	2·38
Idling time (min/13·5 h)	439	615	61·8

* Including any rumination which occurred during the 13·5 h when feed was on offer.

Table 3. *Efficiency of particle breakdown (⟨C.PART⟩) by red deer fed fresh perennial ryegrass or chicory. (Mean values with standard error for five animals per forage in each period)*

	Period 1			Period 2		
	Perennial ryegrass	Chicory	S.E. (D.F. = 8)	Perennial ryegrass	Chicory	S.E. (D.F. = 8)
Ruminating time (min)						
All deer	44·5 (5)*	4·9 (5)	12·67	82·2 (5)	14·0 (5)	26·19
Ruminating†	55·6 (4)*	8·2 (3)	14·98	82·2 (5)	70·0 (1)	55·39
Efficiency of particle breakdown ⟨C.PART⟩						
All deer	0·37 (5)	0·63 (5)	0·067	0·47 (5)	0·65 (5)	0·038
Ruminating	0·38 (4)	0·63 (3)	0·095	0·47 (5)	0·62 (1)	0·050
Non-ruminating	0·24 (1)*	0·64 (2)	—	0	0·65 (4)	—
Fractional degradation of particles > 1 mm (%/h)						
All deer	5·3 (5)	9·3 (5)	0·78	4·9 (5·0)	9·2 (5)	0·67
Ruminating†	5·7 (4)	9·7 (3)	0·73	4·9 (5)	5·9 (1)	0·71
Non-ruminating	3·6 (1)	8·6 (2)	—	0	9·9 (4)	—
Fractional disappearance total DM (%/h)						
All deer	5·2 (5)	10·9 (5)	0·86	5·3 (5)	9·6 (5)	0·66
Ruminating†	5·5 (4)	11·3 (3)	0·71	5·3 (5)	7·1 (1)	0·62
Non-ruminating	3·7 (1)	10·7 (2)	—	0	10·2 (4)	—

* Number of animals in each forage.
† Error D.F. = 5.

of rumen contents in deer fed each diet was similar in each period. In the samples of rumen contents taken at FB, there was a greater proportion of particles > 1 mm in deer fed perennial ryegrass (P = 0·09), largely due to more particles being retained on the 2 mm sieve than in deer fed chicory (P < 0·05;

Table 4. *Rumen pool size and particle size distribution (% DM retained on each sieve) at first baling and second baling in red deer fed perennial ryegrass and chicory for both periods. (Mean values with their standard error)*

Sieve size (mm)	Period	Perennial ryegrass	Chicory	S.E. (D.F. = 8)
First baling (FB)				
Pool size > 1 mm (g DM)	1	220·1	270·0	25·32
	2	264·6	285·0	23·36
Particle size distribution	1+2			
> 2·0		29·6	17·9	4·26
1·0		3·5	4·3	0·53
0·5		4·4	6·0	0·49
0·25		10·2	12·2	0·77
< 0·25		52·2	59·6	3·97
> 1·0		33·2	22·2	4·30
< 1·0		66·8	77·8	4·30
Second baling (SB)				
Pool size > 1 mm (g DM)	1	138·3	96·5	25·32
	2	140·0	98·6	10·91
Particle size distribution	1+2			
> 2·0		24·9	17·2	4·2
1·0		3·6	5·2	0·8
0·5		4·4	8·6	0·7
0·25		10·4	11·2	1·1
< 0·25		56·7	57·8	3·5
> 1·0		28·6	22·4	3·9
< 1·0		71·4	77·6	3·9

Table 4). These differences had disappeared in the samples taken at SB, with the proportion of particles > 1 mm and > 2 mm being similar for the deer fed each forage.

DISCUSSION

The most important results of this study were that the efficiency of particle breakdown (⟨C.PART⟩) in the rumen of swallowed plant material was much greater for chicory (mean 0·62) than for perennial ryegrass (mean 0·42) and that the values of (⟨C.PART⟩) for chicory were similar in deer that did or did not ruminate, whereas lower values were recorded for perennial ryegrass in the deer that did not ruminate. Ulyatt *et al.* (1986) showed that the action of the teeth during eating and rumination was essential for particle size reduction in sheep fed fresh grasses and legumes, and that rumen fermentation weakened plant material but did not reduce particle size. However, the present studies have shown that in some deer chicory disintegrates rapidly in the rumen without action of the teeth during rumination. Hence, very little, and in some cases no, rumination was required for swallowed chicory to break down in the rumen to below the critical particle size for passage from the rumen. The reason for these differences was that chicory contained a higher ratio of readily fermentable carbohydrate: structural carbohydrate than perennial ryegrass (1·37 *v.* 0·39; $P < 0·01$; Table 1). Particle breakdown presumably occurred due to rumen fermentation and to the mixing action of muscular reticulo-ruminal contractions. This also may account for the higher DM, OM and energy digestibilities of chicory than of perennial ryegrass (Hoskin *et al.* 1995). The (⟨C.PART⟩) for perennial ryegrass found in the present study (0·42) was similar to that reported for sheep, whilst the (⟨C PART⟩) for chicory (0·64) was similar to that found for lucerne (0·63) in sheep (Ulyatt *et al.* 1986). It is interesting to note that the (⟨C.PART⟩) of perennial ryegrass was considerably reduced when the deer did not ruminate, implying that action of the teeth during rumination was crucial to reduce particle size of this forage to < 1 mm as shown by Ulyatt *et al.* (1986) for sheep. Deer fed chicory had a greater chewing rate (97·4 *v.* 81·0 chews/min) and more chews/g dry matter intake (36·2 *v.* 31·5) during eating than those fed perennial ryegrass, showing that more comminutive work may be done to chicory before swallowing than to perennial ryegrass. However, despite this, the efficiency of particle breakdown during eating (⟨C.EAT⟩) was still less for deer fed chicory (0·27) than for those fed perennial ryegrass (0·37; Dryden *et al.* 1995), showing that in deer fed chicory the main functions of chewing during eating are to form a bolus for swallowing and to break down the surface of the plant. Although the total eating time of deer fed chicory was similar to those fed perennial ryegrass (209 *v.* 221 min/13·5 h), ruminating time was consistently lower in deer fed chicory compared to those fed perennial ryegrass (30

v. 257 min/22·5 h; Table 2), confirming previous work by Hoskin *et al.* (1995) and Kusmartono *et al.* (1996). Kusmartono *et al.* (1996) found that deer grazing chicory had a higher VFI than those grazing perennial ryegrass/white clover pasture. This can be explained by the fractional degradation of large particles to small particles and the fractional disappearance of DM from the rumen both being approximately twice as fast for deer fed chicory than those fed perennial ryegrass. This provides a faster clearance of DM from the rumen and hence opportunity for increased VFI, as digesta clearance from the reticulo-rumen has long been recognized as a major process determining intake and nutritive value of forages (Black *et al.* 1982).

It can be concluded that chicory can be broken down faster in the rumen, with less rumination being required than in deer fed perennial ryegrass. The rapid disintegration of chicory in the rumen led to a faster rate of DM disappearing from the rumen. Future research needs to be done to partition fractional disappearance rate into its components, rumen fractional degradation rate and rumen fractional outflow rate, to gain further knowledge of the digestion kinetics of chicory and their relationship to nutrient supply and to VFI.

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