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Revisiting particle kinetics in the rumen: comminution, digestion and passage functions as affected by diet type

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Abstract. Six Rasa Aragonesa wethers were fed lucerne hay either chopped at 5 cm (diet C) or ground (2 mm) and pelleted (diet P) in a cross-over design. Access to the diets was restricted to 4 hours, and fractional outflow rates from the rumen of liquid- (Co-EDTA) and solid-phase (Cr and Yb) markers, and digestion kinetics of different particle sizes (0.5-1 mm, 1-2 mm, 2-4 mm and 4-8 mm) were studied. Samples of rumen content were obtained at different times throughout the day to estimate rumen pools of different particle sizes, and dilution rates of transit markers and rumen volume. Feeding behaviour of the animals was also recorded. Dry matter intake was lower (P<0.001) in animals fed diet C than P (1206 *vs.* 1733 g/day) which on the other hand spent more time eating (218 *vs.* 94 min/day, or 182 *vs.* 55 min/kg dry matter intake-DMI; P<0.001) and ruminating (283 *vs.* 182 min/kg DMI; P<0.05). Potential degradability of different particle sizes did not change across diet types whereas fractional degradation rate decreased (P < 0.01) as particle size increased. The mean particle size of rumen digesta was higher with diet C (P < 0.05) whereas the rate at which particles larger than 1.2 mm reduced due to chewing during eating was higher with diet P than C, but the effectiveness of rumination in reducing particle size of rumen digesta was higher with diet C. The higher intakes in animals fed diet P could be explained by variations in rumen volume, rates of digestion and a higher rate of outflow of small particles pulled out with the liquid phase.

Keywords. Degradation – Feeding behaviour – Particle size – Transit.

Revoir la cinétique des particules dans le rumen : diminution de la taille de particule, digestion et passage affectés par le type de régime

Résumé. *Six moutons castrés de race Rasa Aragonesa ont été alimentés avec une ration á base de foin de luzerne soit haché á 5 cm (régime C) ou bien broyé (2 mm) et granulé (régime P) dans un modèle croisé. L'accès aux rations a été restreint á 4 heures, et le taux de passage fractionnaire des marqueurs de la phase liquide (Co-EDTA) et solide (Cr and Yb) de rumen, et la cinétique de la digestion de différentes tailles de particules (0,5-1 mm, 1-2 mm, 2-4 mm et 4 -8 mm) ont été étudiés. Des échantillons de contenu ruminal ont été obtenus à différents moments tout au long de la journée pour estimer les différentes tailles de particules de pools de rumen, et la dilution des marqueurs de transit et le volume du rumen. Le comportement alimentaire des animaux a été également enregistré. L'ingestion de la matière sèche a été plus élevée (P <0.001) chez les moutons alimentés par la ration P en comparaison á ceux alimentés par la ration C (1733 vs. 1206 g/jour) qui ont au contraire passé moins de temps à manger (94 vs. 218 min/jour, ou 55 vs. 182 min/kg de matière sèche ingérée-MSI, P <0,001) et á ruminer (182 vs. 283 min / kg MSI, P <0,05). La dégradabilité potentielle des différentes tailles des particules n'a pas été changée pour les différents types de régime, alors que le taux de dégradation fractionnelle a été diminué (P <0,01) lorsque la taille des particules a été augmentée. La taille moyenne des particules du digesta de rumen a été plus élevée avec le régime C (P <0,05) alors que le taux auquel des particules de plus de 1,2 mm ont été diminués dû á la mastication pendant la consommation a été plus élevée avec le régime P par rapport au régime C, mais l'efficacité de la rumination dans la réduction de la taille des particules du digesta de rumen a été plus élevée avec le régime C. L'ingestion plus élevée chez les animaux nourris avec le régime alimentaire P pourrait s'expliquer par des variations du volume de rumen, le taux de digestion et le taux élevé de passage des petites particules qu'ont été retirées avec la phase liquide.*

Mots-clés. *Dégradation – Comportement alimentaire – Taille des particules – Passage.*

I – Introduction

The amount of a determined feedstuff that can be ingested by a determined animal will depend on both the intrinsic properties of the former (chemical composition and organoleptic characteristics; Minson, 1982) as well as on the intake capacity of the latter (Weston, 1982), and the interaction between those two factors with the environment (Mertens, 1987). Although intake by ruminants can be driven by metabolic or physical signals (Baile and Forbes, 1974; Dulphy and Faverdin, 1987), it seems sufficiently proven that in animals fed low-quality roughages the limiting factor is rumen fill (Conrad *et al*., 1964; Montgomery and Baumgardt, 1965). This rumen fill is in turn related to the rate and amount of intake, and to the rate and amount of digesta flow out of the rumen.

Rate and amount of intake is highly variable (Dulphy and Faverdin, 1987) depending mainly on pattern of intake but also on chemical and physical characteristics of the diet, level of feeding, animal species and physiological state, and environmental conditions. In turn, rate and amount of digesta flow out of the rumen will be determined by digestion and passage. Digestion is the result of comminution through chewing during eating and rumination (Pond *et al*., 1987), and subsequent microbial degradation (Hanna *et al*., 1973), whereas passage refers to the flow of undigested feed residues from one compartment to the next (Warner, 1981).

Classical reviews (Hungate, 1966; Kotb and Luckey, 1972; Warner, 1981; Ellis *et al*., 1988) have pointed out that the study of transit kinetics is not easy, and require an exact knowledge of the amount of the undigestible fraction present in a determined compartment, as well as its rate of incorporation and release, and the assumption that the potentially digestible fractions will show the same kinetic behaviour, or the use of reference substances generally known as markers, which theoretically behave in the same way as the fraction to which they are supposed to be attached. The use of these substances is based on the assumption that rumen volume remains constant, and that inflows to and outflows from the compartment are homogeneous, continuous and equivalent (Faichney, 1975; Ellis et *al*., 1984), although it is known that these ideal conditions are rarely accomplished. The structure of the rumen digesta does not allow an instantaneous and homogeneous mixing of its liquid and solid phases hence different markers with distinct physical-chemical characteristics are needed.

Regardless the methodological aspects, both intraruminal and extraruminal elements affect transit kinetics. Among the latter, dietary (chemical composition, form of presentation) and animal (genetics, age, physiological state) factors, as well as the interaction between them (level of feeding) or with the environment are the most important. Among intraruminal factors, particle size and shape are supposed to be the most limiting factors of digesta passage out of the rumen (Poppi *et al*., 1980; Ulyatt *et al*., 1986) but there is generally a lack of information about how diet type and feeding conditions affect these variables. On the other hand, the relationships between particle size and digestion and passage kinetics are not sufficiently clear as it is not the effect of rumen digesta particle size on marker dilution kinetics in the rumen. Despite that, the number of papers published in this subject in the last two decades appears negligible.

On these grounds, the aim of the present experiment was to study the daily evolution of digesta particle size in the rumen and its relationship with feeding behaviour, digesta load, and digestion and transit kinetics in sheep fed lucerne hay either chopped or ground and pelleted.

II – Materials and methods

In a changeover design, lucerne hay either chopped at 5 cm (diet C) or ground (2 mm) and pelleted (diet P) was offered to six individually-housed Rasa Aragonesa wethers (four years old and with an average live weight of 48.9 ± 1.58 kg at the beginning of the experiment) fitted with a rumen cannula (5.3 mm I.D.). Access to the diets was restricted to 4 hours to allow for daily variations in rumen volume, and fractional outflow rates from the rumen of liquid- (Co-EDTA) and solid-phase (Cr-mordanted and Yb-labelled feeds) markers, and *in situ* degradation kinetics of different particle sizes (0.5-1 mm, 1-2 mm, 2-4 mm and 4-8 mm, obtained by grinding different samples of the lucerne hay through the higher-size meshes, and then sieving through both the higher- and the smaller-size sieves) were studied. Transit markers were introduced via cannula just before feeding (09:00 h). Samples of rumen content were obtained at different times throughout the day to estimate rumen pools of different particle sizes, and dilution rates of transit markers and rumen volume. Feeding behaviour of the animals was also recorded by visual observation.

All results were subjected to a one-way analysis of variance. Differences between treatment means were identified by the least significant difference (LSD). Statistical analysis was performed using the SAS statistical package (version 8.01).

III – Results and discussion

Dry matter intake was lower (P<0.001) in animals fed diet C than P (1733 *vs.* 1206 g/day) which also spent more time eating (218 *vs.* 94 min/day, or 182 *vs.* 55 min/kg dry matter intake-DMI; P<0.001) and ruminating (283 *vs.* 182 min/kg DMI; P<0.05) (Table 1). Potential degradability of different particle sizes did not change across diet types (P > 0.05) whereas fractional degradation rate decreased (P < 0.01) as particle size increased (Table 2). The mean particle size of rumen digesta was higher with diet C (0.89 *vs*. 0.39 mm; P < 0.05) whereas the rate at which particles larger than 1.2 mm reduced due to chewing during eating was higher with diet P than C, but the effectiveness of rumination in reducing particle size of rumen digesta was higher with diet C (Table 3). The higher intakes in animals fed diet P could be explained by variations in rumen volume, rates of digestion and a higher rate of outflow of small particles pulled out with the liquid phase.

Table 1. Dry matter intake (DMI), and times spent chewing during eating and ruminating by wethers fed lucerne hay either chopped at 5 cm (diet C) or ground (2 mm) and pelleted (diet P). Access to the feed was restricted to 4 hours

	Diet C	Diet P	RSD	*P*
DMI (g/day)	1206	1733	39.1	< 0.001
Eating				
min/kg dry matter intake	182	55	7.5	< 0.001
min/day	218	94	10.7	< 0.001
Ruminating				
min/kg dry matter intake	283	182	43.3	< 0.05
min/day	344	318	69.5	> 0.05

RSD: residual standard deviation of the mean of the analysis of variance.
P: probability of the differences.

Table 2. Degradation characteristics (*a* represents the soluble fraction, *b* the insoluble but potentially degradable fraction, and *c* the fractional rate of degradation) of different particle size populations in the rumen of wethers fed lucerne hay either chopped at 5 cm (diet C) or ground (2 mm) and pelleted (diet P). Access to the feed was restricted to 4 hours

	Particle size (mm)	Diet C	Diet P	RSD	*P*
a (%)	0.5-1.0	15.77	17.61	4.780	> 0.05
	1.0-2.0	14.02	17.92	1.541	< 0.01
	2.0-4.0	15.91	16.61	1.559	> 0.05
	4.0-8.0	13.28	15.60	2.360	> 0.05
b (%)	0.5-1.0	41.21	38.43	4.214	> 0.05
	1.0-2.0	43.46	38.96	1.256	< 0.001
	2.0-4.0	40.10	39.21	1.922	> 0.05
	4.0-8.0	40.28	38.65	2.809	> 0.05
c (h^{-1})	0.5-1.0	0.114	0.093	0.0201	> 0.05
	1.0-2.0	0.121	0.086	0.0110	< 0.001
	2.0-4.0	0.087	0.084	0.0143	> 0.05
	4.0-8.0	0.105	0.071	0.0063	< 0.001

RSD: residual standard deviation of the mean of the analysis of variance.
P: probability of the differences.

Table 3. Rate of reduction of digesta particles below a size of 1.2 mm (g/h and%) during eating and ruminating in wethers fed lucerne hay either chopped at 5 cm (diet C) or ground (2 mm) and pelleted (diet P). Access to the feed was restricted to 4 hours

	Diet C	Diet P	RSD	*P*
Chewing during eating				
g/hour	159	294	39.6	< 0.001
%	67.8	91.4	3.74	< 0.001
Ruminating				
g/hour	48.6	9.4	6.69	< 0.001
%	23.8	6.0	3.41	< 0.001

RSD: residual standard deviation of the mean of the analysis of variance.
P: probability of the differences.

IV – Conclusions

Reducing the particle size of lucerne hay increases its intake, and this is related to changes in feeding behaviour, rumen volume, rate of degradation of feed particles in the rumen, and behaviour of different particles which can show a liquid-like (small particles) or a solid-like (large particles) rate of outflow from the compartment.

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