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Effects of Frequency of Meals on Energy Utilization and Body Composition of Sheep Ingesting Diets of Equal Amount

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給食回數가 緬羊의 熱量代謝 및 組織의 化學的成分에 미치는 영향

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Summary

Two experiments with 32 sheep were conducted to study the effects of feeding the same amount of diet per day at different meal frequencies on ration digestibility, energy utilization, rate of gain, body composition and efficiency of gain. The results obtained are as follows:

(1) The ingestion by sheep of the same amount of feed per day in 8 meals, 1 meal plus 7 ruminal inflations-deflations, and in 1 meal caused no different effect in the digestibility of the nutrients and energy, or the ME value of the diet.

(2) Heat production per unit of metabolic size per unit of dietary intake was markedly lower for sheep ingesting 8 meals or administered 1 meal plus 7 ruminal inflations-deflations per day than for sheep fed 1 meal per day.

(3) Body weight gain was significantly greater by sheep fed 8 meals per day or 1 meal plus 7 ruminal inflations-deflations than by those fed 1 meal per day. However, the gain in DM and energy of wool was not affected by frequency of meals.

(4) Sheep ingesting 8 meals or administered 1 meal plus 7 ruminal inflations-deflations per day gained body protein, fat and energy at a more rapid and efficient rate than sheep fed 1 meal per day.

(5) Sheep fed 8 meals per day gained greater proportion of fat, protein and ash in the gained portion of the bodies than did 1 meal fed sheep.

(6) An attempt was made to establish the possible explanations by which the frequency of ingesting meals exerts its effects.

Introduction

The first study of Gordon and Tribe in 1952 and a number of subsequent studies (Hardison et al., 1957; Clark et al., 1962; Mochrie et al., 1956 Rakes et al., 1957, 1961) showed that the feeding of the same amount of feed per day in frequent meals (6 to 10 per day) results in a faster rate of body gain in young rumiants than the feeding of one or two meals per day.

In some experiments in which the body gain response was not observed the animals employed were more mature (Rhodes et al., 1962; Campbell et al., 1961; Rakes et al., 1961; Mochrie et al., 1959). In experiments in which the diet was fed ad libitum levels the effect of frequency of feeding could be confounded with that of the level of feed intake (Clark et al., 1962; Campbell et al., 1961; Mohrman et al., 1959).

Recently it was observed that the frequency of feeding had no effect on the rate of body weight gain of swine (Melnikov et al., 1956). rats (Cohn et al., 1957, 1959, 1963) and chicks (Feigenbaum et al., 1962). It was alse reported, however, that the rats fed two meals per day the same amount of diet ingested by ad libitum rats gained considerably more of body fat. Only one study has demonstrated a lower heat increment in frequently fed sheep than in those fed one or two meals, and no studies on the effect of meal frequency on the body composition of sheep have been made.

Since the absorbability of nutrients has not been effected by meal frequency in any of the animals studied (Rakes et al., 1961; Blaxter et al., 1959; Rhodes et al., 1962; Satter et al., 1962; Cohn et al., 1960), the effect appears to be attributable to occurrances after absorption.

The objectives of present study were: (1) to study the influence of the frequency with which meals are ingested by sheep on (a) the digestibility of nutrients, (b) the utilization of energy and (c) the change in the weight and chemical copmosition of body; (2) to relate these finding to possible mechanisms by which the frequency of meals affects animal response.

Experimental

1. Nature and design of experiments

Two experiments were conducted with sheep of two breeds (Suffolk and Corriedale) fed the same diet in one and eight meals per day and in 1 meal plus ruminal inflation at 7 intervals of the day in Expt I, and in one and eight meals per day in Expt II. The level of feed provided to the individual animals of each trio in Expt I and to each member of the pairs in Expt II was the same.

The factorial design of Expt I (2 breeds X 3 treatments) and that of Expt II (2 breeds X 2 treatments), and the number of sheep employed in both experiments are shown in Table 1.

Table 1. Design of Experiment I and II

Expt. No.	Treatment imposed					
	1 meal		8 meals		1 meal+ 7 inflations	
	Suff.	Corr.	Suff.	Corr.	Suff.	Corr.
I	2	2	2	2	2	2
II	2	2	2	2	—	—

2. Experimental animals and periods

The experimental sheep were selected from purebred population of 24 Suffolks and 24 Corriedales purchased in June, 1963 at an average age of about 4 months and a mean weight of 23 kg.

Experiment I and II were started on July 24, 1964 and carried out during periods of 78 and 134 days, respectively

3. Formula and composition of diets

Total diet cosnisted of approximately 85% pellets and 15% of second-cut alfalfa hay. The pelleted diet fed to the sheep consisted of the following ingredients (%): alfalfa hay, 55.0; wheat middlings, 17.5; linseed meal, 2.0; corn meal, 18.5; molasses, 5.5; salt 0.5; and mineral mix, 1.5.

The average proximate chemical composition and gross energy (GE) value of the diets fed are shown in Table 2.

Table 2. Chemical composition and GE value of diets

Expt. No.	Diet	GE	Protein	Ether Extract	Carbohydrate	Ash
		Kcal/gm	%	%	%	%
I	Pelleted ration	4.291	16.59	2.50	72.03	8.88
II	Alfalfa hay	4.250	17.63	1.22	74.51	6.64

4. Methods of managing and feeding

During a period of three weeks prior to the beginning of Expt I and II, the lambs were fed individually in metabolism cages. An attempt was made to train them to ingest a given meal within an hour, but at a level of intake that could produce a rate of gain of 0.15 kg. or more per day.

Feed intake was adjusted weekly to supply the same amount of feed per unit of metabolic size ($Weight^{0.734}_{kg}$) to the lowest level ingested by member of a given trio or pair.

The sheep fed 1 meal per day received the hay at 8:00 AM and the pelleted ration at 8:00 AM. The animals fed 8 meals per day received the first meal of hay and pellets at 8:00 AM and the remaining equal portions of the ration at 70-minute interval. Fresh water and salt were always available to these groups of animals.

At 7:10 AM the hay allowance was given to the sheep which received the ruminal inflation and at 7:30 AM the pelleted protion of the diet was fed. The ruminal inflations were administered 7 times during the day at the same times that the frequent fed animals received their last seven meals. Water was offered at three times each day, 8:15 AM, 12:00 noon, and 4:30 PM.

The inflation treatment consisted of inflating with water a rubber football bladder placed in the rumen via a permanent fistula. Depending upon the feed intake of his mates, the animal receiving the inflation treatment was administered 500 to 800 ml of water. The water was pumped in during a 20-minute period, left in the rumen for 20 to 25 minutes and finally pumped out slowly during 20-minute period. This treatment was applied seven times per day. A vacuum pump, allowing the flow of air to be reversed, facilitated the pumping or suction movement required. This process was intended to simulate filling and empting of the rumen as it might occur in frequent feeding.

A permanent rumen fistula was prepared in each of 8 sheep four weeks before the beginning of Expt I, according to the method outlined by Dougherty (1955). The fistulae were fitted with cannula, 2.5cm in diameter, through which the football bladder was inserted.

All lambs were shorn two days prior to the beginning of the experiments and just before the end of experiments.

Total intake of diet, GE and ME is shown in Table 3.

5. Metabolism experiment

During the last seven days of the experiment, feces and urine were collected at 8:00 AM each day. Total feces output by animal was dried at 80°C for 48 hours and, at the end of the trial, compounded and weighed. A 20% aliquot of the mixed composite sample was then dried for an additional 24 hours to determine absolute DM of feces. After grinding in a Wiley mill, the feces were stored in sealed containers for subsequent analyses.

Tabel 3. Average intake of diet, GE and ME

Expt. No.	No. of days	Treatment	Total intake of		
			Diet	GE	ME
			kg/$W_{kg}^{0.734}$	kcal/$W_{kg}^{0.734}$/day	
I	78	1 meal	61.03	301	140
		8 meals	6.083	300	140
		1 meal+7 infl.	5.955	294	137
II	134	1 meal	10.551	303	144
		8 meals	10.313	297	142

Total quantity of urine excreted during 24-hour period was collected with rinsings of water sprayed over the surface of the urine pan, and the volume measured. An aliquot of 5 to 10% depending on the total volume vioded was stored at 23°C until the end of trial. The urine was then acidified to a pH of 3 to 4 with sulfuric acid and stored at 23°C. Each morning before feeding, the feed refused during the previous 24-hour period were weighed and sampled.

6. Slaughter- analysis methods.

Prior to the beginning of the experiments the sheep were sorted into 6 groups by the size of animals. From each of these groups one animal was selected randomly to represent the body composition at the beginning of experiment. Thus, 6 sheep represented the initial body composition of breed population. At the termination of the experiments, these animals were slaughtered and analyzed.

The mechanics of slaughtering and of tissue preparation and sampling began with the measurement of the shrunk body weight (SBW) after a period of 18 to 20 hour fast. The animals were bled by severing the major blood vessels in the neck and the blood was collected in large pans. Ingesta was removed from the gastrointestinl tract and weighed; this allowed the empty body weight (EBW) to be measured.

The sheep slaughtered were seperated into the following body parts: (a) total carcass, including head, blood, hide and all visceral parts, (b) contents of the reticulo-rumen and (c) contents of the omasum, abomasum and intestines. Then the body parts were minced and sampled. The samples covered with tin foil were weighed and stored at 23°C until processed further.

Later, samples were freeze-dried until a constant weight was obtained on two consecutive days. The dried samples were then broken into small pieces and ground with dry ice through Wiley mill equipped with 1.59 mm screen. Then the dried, ground samples were stored at 23°C.

7. Chemical methods

The nitrogen content of feed, refused feed, feces, urine and body tissues was determined by means of the macro-Kjeldahl method as outlined by A.O.A.C. (1960) with the boric acid modification proposed by Scales and Harrison (1920). Urine was analyzed in liquid form and all other materials were analyzed in dry form. Dry matter concentration was determined by oven at 100°C for 24 hours. Body tissues and urine were freeze dried.

Fat was determined as the difference in weight between the freeze dried sample and dried residue remaining after extraction with ether.

After the ether extraction had been completed, the crucibles and their contents were ignited at 600°C for 2 days. The residue remaining was recorded as ash.

Heat of combustion values were determined on one to two grams samples with an adiabatic bomb calorimeter.

Results and Discussion

1. Digestibility and metabolizability of nutrients and energy.

Average coefficients of apparent digestibility are seen in Table 4. It is concluded that no difference in the digestibility of DM, protein, fat or carbohydrate and energy attributable to frequency of meals was mathematically significant.

These findings support the observations of Rakes et al. (1957, 1961), Rhodes et al. (1962), and Satter et al. (1962), who also reported that frequency of meals has no effect on digestibility. On the other Gorden et al. (1957), and Moir et al. (1957) observed slightly higher digestion coefficient for certain diets when diets were fed frequently.

Table 4. Digestibility of various nutrients and energy

Expt. No.	Treatment	Digestion Coefficients					
		DM	Protein	E.E.	Ash	Carb	GE
		%	%	%	%	%	%
I	1 meal	59.89	67.85	77.32	45.08	59.30	57.88
	8 meals	61.35	69.63	77.96	41.72	61.09	60.32
	1 meal+ 7 infl.	59.51	99.20	77.61	41.50	58.90	59.16
II	1 meal	65.43	71.25	78.64	40.19	66.34	65.03
	8 meals	63.95	71.13	75.50	43.99	64.15	63.31

Energy losses in urine or combustible gases and ME values of diets are summarized in Table 5. In this table urinary energy and calorific value of methane were computed by the equations proposed by Paladines et al. and Swift et al. (1954), respectively.

No significant difference attributable to frequency of meals was observed in the estimated losses of

Table 5. Energy losses in urine or methane and ME valve of diet.

Expt. No.	Treatment	Fnergy losses		ME value	
		Urine	Methane	Kcal	% of GE
		% of GE			
I	1 meal	6.04	6.03	2446	45.81
	8 meals	7.41	6.40	2183	46.52
	1 meal+ 7 infl.	6.20	6.15	1993	46.82
II	1 meal	5.63	6.72	2556	52.58
	8 meals	5.90	6.54	2427	50.89

either urinary or gaseous energy. Consequently, the ME value of diets was not different for feeding frequencies imposed.

2. Heat production of sheep affected by frequency of meals.

Heat production of sheep was obtained by body balance method. The computation rests in the law of conservation of energy and, thus, heat production is equal to the dietary energy minus the sum of energy loss and, thus, heat production is equal to the dietary energy minus the sum of energy of excreta and body gain.

The mean heat poduction value is shown in Table 6.

Total heat prodruction per unit of metabolic size per day and as percentages of the dietary energy ingested were considerably lower for sheep fed 8 meals per day or those administered 1 meal plus 7 ruminal inflation-deflations than for sheep fed 1 meal per day.

Table 6. Heat production

Expt. No.	Treatment	Heat production	
		per MBS	% of GE
		$kcal/W_{kg}^{0.734}/day$	%
I	1 meal	117.8	39.15
	8 meals	103.8	34.61
	1 meal+7 infl.	110.6	37.61
II	1 meal	110.9	36.60
	8 meals	104.5	35.22

These observations support the finding of Rakes et al. (1961).
They reported that the amounts of heat produced by younger sheep fed 1 meal and 8 meals per day were 127 and 119 kcal per unit of metabolic size per day, respectively.

3. Body weight gain and wool production

It was found that the frequency of feeding had a beneficial effect on the rate of body gain as shown in Table 7.

Table 7. Body weight gain and wool production

Expt. No.	Treatment	FBW gain per MBS	Wool production	
			DM gain	Energy gain
		kg	$gm/m^2/day$	$kcal/m^2/day$
I	1 meal	0.6495	10.39	52.800
	8 meal	0.7918	10.84	55.435
	1 meal+7 infl.	0.7359	10.92	51.529
II	1 meal	1.0882	10.48	50.498
	8 meal	1.1636	9.19	43.467

Sheep fed 8 meals per day gained considerably more of body wight than did those fed 1 meal per day. Sheep administered 1 meal+7 ruminal inflations also gained more body weight than did sheep fed 1 meal per unit of time. These differences nearly approached significance at the 5% level of probability. These data support the earlier findings of Rakes et al. (1957, 1961), Gordon et al. (1952), Mochrie et al. (1959), Clark et al. (1962), who also found that the same amount of diet provided in frequent meals results in a faster rate of gain.

As shown in Table 7, gain in DM and energy of wool was not affeced by the freguency of meals, althouqh Corriedle sheep gained significantly ($P< 0.005$) more DM and energy of wool than did Suffolks.

4. Change in body composition and gain efficiency of weight, protein, fat and energy as affected by frequency of meals.

The amounts and proportions of gain attributable to water, protein, fat and ash are shown in Table 8

The proportion of the gain consisting of water

Table 8. Changein body composition in ingesta-and wool-free sheep bodies

Expt. No.	Treatment	Body gain attributable to:							
		Water		Protein		Fat		Ash	
		Wt.	% gain	Wt.	% gain	Wt.	% gain	Wt.	% gain
		gm	%	gm	%	gm	%	gm	%
I	1 meal	3574	60.90	502	8.29	1760	30.12	44	0.71
	8 meals	3243	47.11	709	11.34	2691	39.32	162	2.26
	1 meal+7 infl.	3348	57.04	622	10.64	1734	30.07	133	2.26
II	1 meal	5306	47.00	1091	9.69	4738	42.32	122	1.00
	8 meals	5320	43.73	1264	10.30	5353	43.91	262	2.09

was significantly ($P<0.005$) greater for the 1-meal fed group than for the those fed 8 meals per day in Expt I. Conversely, those fed 8 meals per day gained greater ($P<0.05$) proportion of fat, protein and ash than those fed 1-meal per day. Similar results were obtained from Expt. II with smaller magnitude in proportions.

A study was made on the effect of frequency of meals on efficiency with which the body gained weight, protein, fat, and energy. The mean gains per unit of metabolic size per kilogram of dietary DM ingested are summarized in Table 9.

Table 9. Gain efficiency of body weight, fat and energy.

Expt. No.	Treatment	Gain*/kg. DM/$W_{kg}^{0.734}$			
		Body Wt	Protein	Fat	Energy
		gm	gm	gm	kcal
I	1 meal	91.9	13.8	25.2	316
	8 meals	116.9	19.6	42.0	510
	1 meal+7 infl.	105.3	17.4	28·6	381
	1 meal	106.5	15.8	40.3	471
	8 meals	115.7	16.1	46.3	540

* Gain represents ingesta-free body and wool

Sheep fed 8 meals or administered 1 meal plus 7 ruminal inflations-deflations per day gained weight, protein, fat and siginificantly ($P<0.005$) more efficient rates than the sheep fed 1 meal per day. In Expt. I the average rates of gain of weight, protein, fat and energy were 27.2, 42.0, 66.7 and 61.4%, respectively, greater for the 8-meal regime than for 1-meal feeding treatment. The advantages of inflations-deflations treatment over the 1-meal regime were 14.6, 13.5 and 20.9%, respectively.

The magnitude of the differences between the two frequencies of meals in Experiment II was somewhat less than that in Experiment I.

The sheep fed frequent meals gained 8.6% more body weight, 8.2% more protein, 14.9% more fat, and 14.7% more energy than the sheep fed 1 meal per day.

5. Mechanisms by which the frequency of meals exerts its effects.

It has demonstrated that the frequency with which meals are ingested had a much different effect on sheep than on the rats. In sheep, 8 meals per day resulted in an increased rate of gain in body weight, fat, protein, ash and energy. Sheep fed 1 meal and administered 7 ruminal inflations-deflations per day gained more body weight, fat, protein, ash and energy than did those fed 1 meal per day, but the most striking differences were in the protein and mineral gains. On the other hand, rats fed infrequent meals gained larger amouts of fat and energy and smaller amounts of protein than those fed ad libitum. Thus, it is obvious that frequent meals had an opposite effect on the gross energetic efficiency of the 2 animal species.

One possible explanation for the effects observed is that the frequency of meals might influence the nature of the digestion products observed. If frequent meals reduce the salivary output the buffering capacity and pH of the rumen would decrease and the propionic acid produced would increase (Balch et al., 1959; Davis et al., 1964). It is well established that propionate is more efficiently used in the lipogenesis than the other volatile fatty acids (Armstrog et al., 1958).

Knox et al. (1960, 1961) showed that the ratio of propionate to acetate produced in the rumen was slightly greater when cows were fed 8 meals per day than when 2 meals were fed. This was confirmed by Putnam et al. (1961) who found that frequent meals also increased the concentration of total volatile fatty acids. On the other hand, Mochrie (1959) and Satter et al. (1962) observed no effect of frequency of feeding on the concentration of ruminal volatile fatty acids. Frequency of feeding also effects the kind of ruminal microorganisms present. Putnam et al. (1961), Moir et al. (1956) and Purser (1961) found that frequent meals resulted in an increased number of ruminal protozoa.

Another possible mechanism for the effects observed in sheep concerns a series of hormonal functions. Young ruminants respond to frequent meals, whereas mature ones do not (Rakes et al., 1957; 1951; Clark et al., 1962; Mochrie et al., 1956; Rhodes et al., 1962; Campbell et al., 1961). In the present studies, the ruminal inflation-deflations, a purely physical treatment, resulted in an increased gain of weight, fat, protein, ash and energy, but the gain in protein and ash were especially pronounced. It is well recognized that the somatotrophic hormone (STH) has a specific function in protein anabolism and mineral deposition (Best and Taylor, 1961). It is suggested that the physical stimulation of the rumen by filling and emptying the rubber bladder might result in the hypothalamus releasing larger than usual amounts of STH to increase the protein and mineral gain of the body.

國 文 要 約

等量의 飼料로서 給食回數를 달리 헷을때 緬羊의 增體, 營養素의 消化率, 熱量利用性, 體組織의 化學成分에 미치는 影響을 硏究하기 위하여 32頭의 緬羊으로 두個의 實驗을 하였든바 그 成績은 다음과 같다.

(1) 營養素의 消化率 및 ME價에 있어서 1日 1回 8給食區, 1日 8回給食區, 1日 1回給食+7回添水區사이에 何等의 差異가 發見되지 않았다.

(2) 每代謝體重當 熱發生量은 1日 8回區가 1回區보다 휠씬 적었다.

(3) 1日 8回區는 1回區보다 增體量이 더 많았다.

(4) 1日 8回區의 경우 體蛋白質, 脂肪, 에너지의 增加가 1回區보다 휠씬 왕성하였다.

(5) 增體된 部分의 體組成 變化를 보면 1回區의 경우에 휠씬 많은 量의 脂肪, 蛋白質, 鑛物質이 비축되었다.

(6) 給食回數가 위에서 본바와 같은 영향을 이르키는 生理的機轉의 一部가 說明되었다.

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