The nutritive value of fat in the diet of the milk-fed lamb

1. The apparent and corrected digestibilities of different dietary fats and of their constituent fatty acids

BY D. M. WALKER AND G. B. STOKES*

Department of Animal Husbandry, University of Sydney, Australia

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1. Thirty-five male cross-bred lambs at 3 d of age were given artificial milks with a protein-calorie concentration of 25 % and containing either lard, coconut fat, cottonseed oil, rapeseed oil, groundnut oil, soya-bean oil, safflower oil, tallow, maize oil or olive oil, homogenized with reconstituted skimmed cow's milk to provide 50 % of the total energy of the diet. Two lambs were given a low-fat diet of reconstituted dried skim milk. All lambs were bottle-fed for 28 d.

2. The dietary fats and oils were highly digestible (97·2–99·5 %) with the exception of lard (89·1 %), rapeseed oil (61·9 %) and tallow (77·8 %). The indigestibility of these dietary fats was related to their content of stearic or erucic acids. The fatty acid patterns of the faecal fat were similar within each dietary group, but differed between diets.

3. Metabolic faecal fat excretion was 4·1 ± 0·5 g/100 g faecal dry matter. There was no similarity between the fatty acid composition of the metabolic faecal fat and that of the faecal lipids excreted by lambs given fat in their diet. The metabolic faecal fat made only a minor contribution to the total faecal lipids, so that the apparent and 'corrected' digestibility coefficients were very similar.

Ewe's milk has a fat content of about 10 % and the fat contributes some 68 % of the total energy to the milk (Perrin, 1958). Whilst it is known that the preruminant lamb is unable to tolerate a high intake of carbohydrate (Walker & Faichney, 1964*b*), there is little known of its ability to digest and utilize different oils and fats. In the present paper values are given for the digestibility by lambs of artificial-milk diets containing oils and fats of widely different fatty acid composition, for the fatty acid composition of the faecal fat, and for the quantity and composition of the metabolic faecal fat.

EXPERIMENTAL

Animals and their management

Thirty-five male cross-bred lambs ((Border Leicester ♂ × Merino ♀) × Dorset Horn ♂) were used. The lambs were born at pasture and were about 3 d of age at the start of the experiment. The mean daily maximum and minimum temperatures in the animal house during the experimental period were 28° and 11° respectively.

The lambs were weighed daily 3 h after the morning feed and live-weight gain was estimated by a regression analysis of the daily weights. The experimental management, collection and storage of faeces were as described for previous experiments (Walker & Faichney, 1964*a*).

* Present address: Department of Biochemistry, N. Carolina State University, Raleigh, NC, USA.

Experimental design

Eleven dietary treatments were used. The experimental period of 4 weeks was divided into four periods. The diets were given for a preliminary period of 4 d (period 1), followed by collection periods of 10 d (period 2), 7 d (period 3), and either 6 or 8 d (period 4). One lamb, that was being fed on the lard diet (diet A), died during period 4 owing to a blockage of the large intestine with a hard pellet of food residues. A second lamb, that was being fed on the soya-bean oil diet (diet F), died of pneumonia during period 3.

The experiment was performed in 2 successive years. In the 1st year diets A–E_1 and K were fed, and in the 2nd year diets E_2–J were fed. The initial live weights of the lambs varied from 2·8 to 5·0 kg. The effects of the dietary treatments on live-weight gain and on the digestibility of the proximate nutrients were estimated by an analysis of variance.

Table 1. *Composition of the diets (per 100 g dry matter)*

Constituent	'Milk' to contain 15% total solids: Diets A and C–J	Diet B*	Diet K
Dried skim milk (g)	70·7	69·6	100·0
Fat (g)	29·3	30·4	—
Crude protein (g)†	26·5	26·1	37·4
Ether extractives (g)	29·9	31·0	0·1
Ash (g)	5·8	5·7	8·1
Nitrogen-free extractives (by difference) (g)	37·8	37·2	54·4
Energy: kcal	581	571	428
MJ	2·43	2·39	1·79
Protein calories as % of total calories	25·4	25·5	48·9

* 15·24% total solids. † N × 6·38.

Diets

The composition of the experimental diets is given in Table 1. Eleven groups of three lambs each were given artificial milks in which the protein source was spray-dried skimmed cow's milk (DSM). Ten neutral fats, namely lard (diet A), coconut fat (diet B), cottonseed oil (diet C), rapeseed oil (diet D), groundnut oil (diets E_1 and E_2), soya-bean oil (diet F), safflower oil (diet G), tallow (diet H), maize oil (diet I) and olive oil (diet J), selected for differences in physical and chemical properties, were homogenized with DSM to provide about 50% of the total energy content of each diet. Protein and carbohydrate each contributed 25% of the total energy. The vegetable oils were commercially refined and deodorized. The proportion of coconut fat in diet C was higher than that present in the other diets, when expressed on a weight basis, to compensate for the lower heat of combustion of this fat.

Two lambs were given a diet of reconstituted DSM (diet K), that was virtually fat-free, to estimate the excretion of metabolic faecal fat.

A concentrated mixture that contained neutral fat, DSM and distilled water in the proportions (w/w) of 2:1:10 was homogenized once weekly in a Weir Junior Homogenizer at a pressure of 850 lb/in^2 and at a temperature of 65–70°. The homogenate was stored at 5°. The antioxidant propyl gallate (n-propyl-3,4,5-trihydroxybenzoate) was added so that the final concentration in the dry matter of the diets when fed to the lambs was 0·05% (w/w). The individual diets were prepared with distilled water every 2 or 3 d and stored at 5°. A trace element mixture that contained $FeSO_4$, $CuSO_4$ and $CoCl_2$ was added to the diets to increase the concentration of these metals in the dry matter by 50 ppm Fe, 5 ppm Cu and 0·1 ppm Co. A vitamin supplement was added to each diet so that the final composition was similar to that of ewe's milk (cf. Walker & Faichney, 1964*a*) with the exception of vitamin E, where the level was raised to about three times that in ewe's milk by the addition of DL-α-tocopherol acetate.

All lambs were dosed with 1 ml of a groundnut-oil solution of 100000 i.u. retinyl acetate and 10000 i.u. ergocalciferol 2 d after the start of the experiment. Aureomycin soluble (0·45 g; Cyanamid of Great Britain Ltd), which contained chlortetracycline hydrochloride (25 mg), was given daily, dissolved in the milk, to each lamb.

The energy values of the diets (cf. Table 1) were calculated from the experimentally determined values of the individual dietary constituents as follows: glucose 3·736 kcal/g (15·63 kJ/g), dried skim milk 4·280 kcal/g, (17·91 kJ/g), coconut fat 9·000 kcal/g (37·66 kJ/g), all other fats and oils 9·500 kcal/g (39·75 kJ/g) (all values expressed on a dry-matter basis).

The lambs were bottle-fed twice daily at 08.00 h and 19.00 h after the diets had been warmed to about 37° by immersion in a constant temperature bath. The energy intake of the lambs was 210 kcal/kg$^{0·73}$ (879 kJ/kg$^{0·73}$) live weight 24 h, and the amount of milk was adjusted three times weekly to allow for any change in live weight. All diets were palatable with the exception of diet D, which contained rapeseed oil. However, when the lambs were removed from the metabolism cages they usually drank this diet enthusiastically.

Analytical methods

Dietary constituents and faeces. Total N, fat, ash, dry matter and energy were determined by the methods of Walker & Faichney (1964*a*). Fatty acids were extracted from the faeces by the method of Bligh & Dyer (1959), with a preliminary acidification with concentrated HCl to pH 4. The fatty acids were methylated by the method of Metcalfe, Schmitz & Pelka (1966). An Aerograph (Model 600-C) gas chromatograph with a hydrogen flame ionization detector was operated isothermally with a column temperature of 190°. Methyl esters were separated using a stainless steel column, 152 cm × 32 mm OD, packed with 10% diethylene glycol succinate on Chromosorb W (80–100 mesh), with nitrogen as the carrier gas. The proportions of individual fatty acids were estimated by the method of Bartlet & Iverson (1966), and confirmed by comparison with standard quantitative mixtures of methyl esters.

RESULTS

The mean values for the live weights, energy intakes and live-weight gains of lambs in all groups and for the apparent digestibility coefficients of energy and of the proximate nutrients (periods 2–4) are given in Table 2. There were no significant differences

Table 2. *Mean values for the live weight, energy intake and live-weight gain of the lambs per 24 h, the apparent and corrected digestibility coefficients of the dietary fat, and the digestibility of the dietary constituents*

						Apparent digestibility coefficients (%)				Fat	
Diet	Dietary fat	No. of lambs	Live weight (kg)	Energy intake* (kcal)	Live-weight gain (g)	Dry matter	Energy	Total N	N-free extractives	Apparent	Corrected
A	Lard	3	6·1	756	125	95·0	93·4	96·3	99·9	88·4	89·1
B	Coconut	3	6·1	781	116	98·3	98·4	96·8	99·5	99·2	99·5
C	Cottonseed	3	6·4	793	118	97·1	97·2	95·6	99·2	97·0	97·5
D	Rapeseed	3	5·4	712	42	81·8	76·8	84·2	97·1	59·4	61·9
E_1	Groundnut	3	6·3	788	123	97·5	97·7	96·6	99·6	97·3	97·7
E_2	Groundnut	3	6·6	816	118	97·5	97·4	95·4	98·4	98·1	98·5
F	Soya-bean	3	4·9	652	102	97·5	96·5	95·2	98·9	97·8	98·2
G	Safflower	3	5·7	724	111	97·0	97·0	93·8	98·3	98·0	98·5
H	Tallow	3	5·4	702	99	89·6	90·1	92·1	97·9	76·3	77·8
I	Maize	3	5·6	720	117	96·7	97·3	94·7	98·4	96·6	97·2
J	Olive	3	5·7	728	121	98·1	97·1	95·9	99·2	98·6	99·0
	SE of group mean	—	±0·3	±29	±5	±0·5	±0·5	±0·6	±0·4	±0·9	±0·9
	Significant difference ($P = 0·05$)	—	1·7	162	31	2·6	2·7	3·2	1·0	5·0	4·8
K	Fat-free	2	5·8	684	106	95·8	96·5	95·0	98·5	—	—

* 1 cal = 4·184 J.

Table 3. *Mean values (three estimations) for the fatty acid compositions (wt %) of the dietary fats*

Fatty acid	Lard	Coconut	Cottonseed oil	Rapeseed oil	Groundnut oil	Soya-bean oil	Safflower oil	Tallow	Maize oil	Olive oil
< 12S*	—	10·9	—	—	—	—	—	—	—	—
12:0	—	46·0	—	—	—	—	—	—	—	—
14:0	2·2	15·8	1·0	—	—	—	—	3·3	—	—
16:0	24·8	13·3	20·7	6·5	10·7	8·2	5·9	24·1	13·8	11·1
16:1	4·5	—	—	—	—	—	—	6·5	—	—
18:0	12·9	3·5	3·1	1·3	3·0	6·9	3·1	18·1	—	—
18:1	44·0	7·6	22·1	11·9	35·3	24·1	13·9	44·9	35·3	72·5
18:2	6·6	2·2	49·4	19·6	36·2	51·0	74·3	—	49·2	13·6
18:3	1·6	—	1·1	13·7	2·2	9·6	—	—	—	—
20:0	—	—	—	—	2·3	—	—	—	—	—
22:1	—	—	—	41·2	—	—	—	—	—	—
Total saturated	41·7	89·6	26·6	10·7	24·2	15·3	9·1	45·5	13·8	11·1
Total unsaturated	58·3	10·4	73·4	89·3	75·8	84·7	90·9	54·5	86·2	88·9
Dietary lipid (g/24 h)	40·7	43·3	42·2	37·2	42·0	31·4	34·3	33·0	33·6	33·7

* < 12S = concentration of saturated fatty acids with less than twelve carbon atoms.

Table 4. *Mean values for the fatty acid compositions (wt %) of the faecal lipids (three lambs per group) of lambs given different dietary fats*

Fatty acid	Diet A. Lard	Diet B. Coconut	Diet C. Cotton-seed oil	Diet D. Rapeseed oil	Diet E. Ground-nut oil	Diet F. Soya-bean oil	Diet G. Safflower oil	Diet H. Tallow	Diet I. Maize oil	Diet J. Olive oil	Diet K. Fat-free	SE of group mean
12:0	—	14·3	—	—	—	—	—	—	—	—	—	—
14:0	1·0	19·9	1·0	—	—	—	—	2·2	—	—	5·6	±0·7
16:0	28·0	30·1	36·7	2·0	15·2	13·1	11·1	30·2	27·7	22·2	25·2	±1·1
16:1	1·1	—	2·1	—	—	—	—	6·1	—	1·4	7·6	±0·4
18:0	45·5	17·5	15·9	1·6	11·0	8·3	5·0	37·0	20·1	15·4	18·9	±1·1
18:1	11·6	10·4	20·0	7·0	14·4	29·2	32·8	21·1	37·4	51·8	24·3	±1·7
18:2	—	—	18·4	4·5	1·6	36·2	43·2	2·8	11·6	5·7	—	±1·7
18:3	—	—	—	7·3	—	7·2	—	—	—	—	—	—
20:0	—	—	—	—	6·9	—	—	—	—	—	—	—
22:1	—	—	—	71·0	—	—	—	—	—	—	—	—
> 18S*	8·1	1·9	3·3	2·2	39·8	5·4	—	—	—	—	1·5	—
> 18U*	1·4	1·4	—	75·1	16·2	—	7·4	—	1·4	1·8	6·8	—
Total saturated	84·1	84·8	57·0	5·9	66·7	27·3	16·6	69·5	49·2	38·3	54·5	±1·6
Total unsaturated	15·9	15·2	43·0	94·1	33·3	72·7	83·4	30·5	50·8	61·7	45·5	±1·6
Faecal lipid (g/24 h)	4·6	0·4	1·2	15·2	1·1	0·7	0·7	7·7	1·1	0·5	0·4	—
Faecal dry matter (g/24 h)	6·7	2·4	4·1	22·5	3·5	2·6	3·5	11·5	3·9	2·3	7·8	—

* > 18S, 18U = concentration of saturated and unsaturated fatty acids with greater than eighteen carbon atoms.

between the live-weight gains of the two groups of lambs given diet E in successive years (diets E_1 and E_2), or between the apparent digestibility coefficients of this diet. The results for both years were combined for the analysis of variance. Diets that contained lard, rapeseed oil and tallow were less well digested than all other diets. The reduction in the digestibility of dry matter and of energy in these diets was caused mainly by the lower digestibilities of the ether extractives fraction (cf. Table 2).

Fatty acid composition of dietary and faecal lipids

The tables of fatty acid compositions given in this paper include only the major constituents, comprising > 1%. The minor constituents and fatty acids occurring only in traces have been omitted, to facilitate comparisons between dietary and faecal lipids.

The fatty acid compositions of the dietary lipids are given in Table 3 and those of the faecal lipids in Table 4. The composition of the faecal lipids varied considerably between the dietary treatments. In most instances the faecal lipids had lower concentrations of oleic (18:1) and linoleic (18:2) acids, and higher concentrations of palmitic (16:0) and stearic (18:0) acids, than the corresponding dietary lipids. There were only small differences in faecal lipid composition between the individual lambs given a particular dietary fat, but the faecal fatty acid patterns were always different from those of the lambs given the diet low in fat (diet K). An unidentified peak, that was probably 10-hydroxystearic acid, was observed in the majority of the faecal lipids examined, and especially with dietary fats that were rich in stearic and oleic acids. James, Webb & Kellock (1961) identified 10-hydroxystearic acid, as well as smaller amounts of the 6-, 7-, 8- and 9-isomers, in the faecal lipids of human subjects with steatorrhoea, and attributed their presence to conversion from stearic acid by faecal micro-organisms.

Table 5. *Mean values for the apparent and 'corrected' digestibility coefficients of the constituent fatty acids of lard, rapeseed oil and tallow*

Fatty acid	Lard		Rapeseed oil		Tallow	
	Apparent	Corrected	Apparent	Corrected	Apparent	Corrected
14:0	94·9	96·6	—	—	84·4	86·9
16:0	87·2	87·9	87·4	97·0	56·4	57·8
16:1	—	—	—	—	67·3	69·0
18:0	60·1	61·1	49·8	85·8	28·8	30·3
18:1	97·0	97·4	76·0	81·0	83·6	84·4
18:2	100·0	100·0	90·6	90·6	—	—
18:3	100·0	100·0	78·2	78·2	—	—
22:1	—	—	29·6	29·6	—	—
Total lipid	88·4	89·1	59·4	61·9	76·3	77·8

Apparent and corrected digestibility coefficients

The mean value and standard error for the excretion of fat by the two lambs given the low-fat diet (diet K; periods 3 and 4) was 347 ± 39 mg/24 h ($n = 4$, range 280–460), or $4·1 \pm 0·5$ g/100 g faecal dry matter ($n = 4$, range 3·0–5·2). The latter value was used in calculating the corrected digestibility coefficients.

The apparent and corrected digestibilities of the total dietary lipids are shown in Table 2. With the exception of lard, rapeseed oil and tallow, the digestibilities of all dietary fats were uniformly high, and the metabolic faecal fat made only a minor contribution to the total faecal fat in all lambs. The apparent and corrected digostibilities of individual fatty acids in lard, rapeseed oil and tallow are given in Table 5. The digestibility of a particular fatty acid varied according to its dietary source. This variation was not merely a function of the quantity of that fatty acid in the dietary fat, but was attributable in part to an interaction between the component fatty acids. The indigestibility of rapeseed oil was due mainly to its high content of erucic acid, but other fatty acids in rapeseed oil also had reduced digestibilities. Stearic acid was very poorly digested in lard (61·1 %) and tallow (30·3 %), moderately digested in rapeseed oil (85·8 %) and cottonseed oil (87·8 %), and highly digested in all other fats and oils (groundnut oil, 92·5 %; coconut fat, 96·6 %; soya-bean oil, 98·2 %; safflower oil, 99·3 %—corrected digestibilities).

DISCUSSION

Webb, James & Kellock (1963) with adult human subjects, Bayley & Lewis (1965) with pigs, and Underwood, Hashim & Sebrell (1967) with children, have reported that the fatty acid patterns in the faecal lipids are not affected by the nature of the dietary fat. Webb *et al.* (1963) thought that the composition of the faecal lipids was determined far more by factors peculiar to the individual person than by the dietary fat. Although these authors do not state the total energy intake of their subjects, it may be calculated that on average the dietary fat would not contribute more than 20 % of the total energy of the diet, and frequently much less. In our experiment, when account was taken of the indigestibility of certain fatty acids and the partial hydrogenation of others, the composition of the faecal fat was closely related to that of the dietary fat. In our diets, fat contributed about 50 % of the total energy intake so that, even when the fat digestibility was very high, a significant amount of unabsorbed fat was present in the faeces, though its composition may have been modified by transformations due to microbial activity in the lower gut (cf. Wollaeger, Lundberg, Chipault & Mason, 1953; Bergström & Blomstrand, 1956; Gompertz & Sammons, 1963). The fatty acid patterns of lambs given low-fat diets were different from those of lambs given diets containing more fat. There was no evidence that the faecal fatty acid patterns were peculiar to individual lambs.

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