

## Effects of feeding restriction and meal pattern of a sugar beet-containing diet and control diet on nutrient digestibility, plasma lipid concentrations and postprandial triacylglycerol response in broiler chickens

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Broiler chickens were fed on a control diet based on maize or a diet containing sugar-beet-pulp fibre (Beetfiber) at an inclusion level of 46 g/kg. Diets were provided *ad lib.* or at a restricted level either once daily or three times daily. On days 13 and 20, chickens fed on the *ad lib.* control and sugar-beet-pulp-containing diets generally weighed more and had poorer feed conversion ratios than chickens given the restricted control and sugar-beet-pulp-containing diets respectively. Furthermore, chickens given the restricted diets once daily had greater body weights and generally improved feed conversion efficiencies compared with chickens given the restricted diets three times daily. Generally, elevated plasma lipid concentrations were observed amongst chickens given the restricted diets once daily compared with chickens fed *ad lib.* as well as the restricted diets three times daily, while chickens fed on restricted diets three times daily had plasma lipid concentrations intermediate between those fed *ad lib.* and once daily. In a plasma triacylglycerol response study on day 22, feeding of sugar-beet-pulp-containing diets generally reduced postprandial triacylglycerol concentrations and delayed triacylglycerol response relative to chickens given the control diets either *ad lib.* or restricted, which may indicate gastrointestinal adaptation to feeding of a fibre-rich diet. Postprandial triacylglycerol concentrations observed for chickens receiving restricted diets were increased compared with chickens given the respective *ad lib.* diets, indicating adaptation of chickens to reduced feed frequency. On day 25, feeding of sugar-beet-pulp-containing diets decreased digesta dry matter content and ileal organic matter digestibility. Chickens given sugar-beet-pulp-containing diets generally had, on day 25, increased caecal short-chain fatty acid (SCFA) concentrations in comparison with chickens given the *ad lib.* control diet, indicating increased fermentation of dietary components. It is also noteworthy that the greatest SCFA concentrations were observed amongst chickens given the control diet once daily, suggesting enhanced caecal fermentation capacity. This may have been a consequence of increased bacterial activity and caecal hypertrophy due to infrequent feeding of a low-fibre diet.

Sugar beet: Plasma lipids: Dietary fibre: Feeding frequency: SCFA: Chickens

Hyperlipidaemia is considered a major risk factor in the development of cardiovascular disease (Anderson & Tietyen-Clark, 1986). In recent years the search for dietary means to reduce blood lipid levels as a more desirable alternative to expensive drug therapy has focused research efforts on the effects of dietary fibre on lipid metabolism (Anderson *et al.* 1990; Furda, 1990).

The relative solubility of dietary fibres in water has a profound influence on their effect on lipid metabolism; water-soluble dietary fibres including pectins have well established plasma cholesterol-reducing properties (Chang, 1983; Kritchevsky, 1986). Sugar-beet fibre (Beetfiber) contains approximately 250 g soluble dietary fibre/kg, of which the major part

is pectin, and has been shown to reduce blood triacylglycerol and total plasma cholesterol concentrations in chickens (Pettersson & Razdan, 1993).

Reduced meal frequency or intermittent feeding (i.e. one to two meals daily) is associated with a range of physiological and metabolic effects in animals including stomach and small intestine hypertrophy, increased postprandial plasma insulin levels and enhanced cholesterol synthesis in the liver (Fábry & Tepperman, 1970). Restricted feeding of a low-fibre diet once daily to broiler chickens resulted in a three-fold increase in blood triacylglycerol concentrations in comparison with chickens given a low-fibre diet *ad lib.* (Pettersson & Razdan, 1993). In studies on normal human subjects, increasing meal frequency has been shown to reduce significantly fasting total plasma cholesterol, low-density lipoprotein and apolipoprotein B concentrations (Jenkins *et al.* 1989), while in another study nibbling diets given to non-insulin diabetics reduced significantly plasma triacylglycerol concentrations relative to meals provided three times daily (Jenkins *et al.* 1992).

The present experiment was conducted in order to establish the effects on production results and plasma lipid concentrations in broiler chickens fed on a control diet supplemented with sugar-beet fibre given either *ad lib.*, once daily or three times daily. Ileal digestibility, triacylglycerol concentrations over a 6 h postprandial period and caecal short-chain fatty acid (SCFA) concentration in broiler chickens given diets *ad lib.* or once daily were also analysed.

## MATERIALS AND METHODS

### *Sugar-beet pulp*

Standard dried sugar-beet pulp (Beetfiber) was supplied by the Swedish Sugar Company, Arlööv, Sweden.

### *Diets*

The chickens received a control diet based on maize (405 g/kg feed), or isonitrogenous diets in which part of the maize starch, fish meal, meat-and-bone meal, and animal fat components were substituted with sugar-beet pulp at an inclusion level of 46 g/kg feed (Table 1). Lysine and DL-methionine were included at a level of 1 g/kg in each of the mash diets, milled to pass a 3.5 mm screen.

### *Chickens*

A total of 384 1-d-old broiler chickens (Ross) of mixed sex were divided into twenty-four groups of sixteen chickens with an average group weight of 600 g and a maximum difference in weight of 4 g between groups. The groups were randomly allotted to six four-tier battery cages with raised wire floors in a windowless, light- and temperature-controlled room. The six experimental diets were randomly assigned to four replicates (cages) each. Chickens were wing banded and their sex determined on day 1 of the experiment. Chickens fed on the *ad lib.* control (C) and sugar-beet-pulp-containing (BP) diets had free access to feed and water except for 8 h before collection of serum samples for analysis of plasma cholesterol and triacylglycerol concentrations on days 14 and 21. Chickens fed on the restrictive diets were on days 4–21 given 0.8 of the average total feed intake of the chickens fed on *ad lib.* C or BP diets respectively. Chickens restrictively fed on C and BP diets were fed once daily at 24.00 hours (C-1 and BP-1 diets respectively) except on occasions before blood collection when feed was given at 22.00 hours. Chickens given the C-3 and BP-3 diets received the same quantity of feed as chickens given the C-1 and BP-1 diets respectively, but the feed was divided into three portions which were given to the chickens on three separate occasions each day at 08.00, 16.00 and 24.00 hours (C-3 and BP-3 diets,

Table 1. *Composition of the control and sugar-beet-pulp-containing broiler chicken diets (g/kg air dry basis)*

Diets ...	Control	Sugar-beet pulp
Maize	405.0	405.0
Soya-bean meal	200.0	200.0
Fish meal	40.5	37.8
Meat-and-bone meal	40.5	37.8
Animal fat	18.8	18.8
Sugar-beet pulp	—	46.0
Maize starch	246.2	207.6
Limestone	17.0	17.0
Monocalcium phosphate	13.0	13.0
Vitamin and trace element premix*	10.0	10.0
Salt	3.0	3.0
Cholesterol	2.0	2.0
Lysine hydrochloride	1.0	1.0
DL-Methionine	1.0	1.0

\* For details of composition, see Pettersson & Åman (1992).

respectively). However, the third portion of feed was given at 22.00 hours on occasions before culling.

#### *Production study*

Individual chicken weights and group cumulative feed intake (air-dry weight) were recorded at 13 and 20 d of age and group feed conversion ratios (g feed/g weight-gain) were calculated on a weight-gain basis.

#### *Plasma lipid study*

At both days 14 and 21, chickens were starved overnight (8 h from 24.00 hours) after which two birds from each cage (one of each sex) with weights as close as possible to the average group weight were slaughtered by cervical dislocation. Blood samples were collected from the jugular veins of each chicken for plasma triacylglycerol and cholesterol analyses.

#### *Postprandial plasma triacylglycerol study*

After blood sampling for the plasma lipid study on day 21, dietary restrictions were removed and diets were given *ad lib.* (from 15.00 hours) to all remaining chickens. On day 22, chickens fed on the *ad lib.* C and BP diets as well as the C-1 and BP-1 restricted diets up to this point of the experiment were starved for 3 h after which one chicken from two of the four cages from each diet was chosen randomly and slaughtered by cervical dislocation (at 08.00 hours). Blood samples were collected from the jugular veins of the animals for analysis of fasting plasma triacylglycerols. The remaining chickens involved in this part of the experiment were then given their respective diets *ad lib.* for a 1 h period and feed intake was recorded. After this, one chicken from two of the four cages from each diet was chosen randomly and slaughtered by cervical dislocation, and blood samples were collected as described immediately after feed was removed following the 1 h feeding period (09.00 hours). Further culling occurred at 2, 3, 4, 5 and 6 h after feed was provided. At each cull, one randomly selected chicken from two of the four cages from each diet was killed. Blood samples were collected from each culled chicken at the specified times. At the end of the study, three chickens from each of the remaining two cages from each diet were

relocated to cages previously occupied by chickens used in the triacylglycerol response study in order to replenish numbers for the digestibility study on day 25.

#### *Digestibility study*

From 15.00 hours on day 22, diets were given *ad lib.* with a marker ( $\text{Cr}_2\text{O}_3$ ) incorporated at a level of 4 g/kg. On day 25, one randomly selected bird from each of the cages containing chickens previously given the *ad lib.* C and BP diets as well as the C-1 and BP-1 restricted diets was slaughtered by cervical dislocation. Thereafter, slaughtering occurred every fourth hour for a further 20 h. At each slaughter the gastrointestinal tracts of the chickens were quickly removed and the contents of the last third of the small intestine (denoted ileum) were collected separately, pooled for each group, frozen ( $-25^\circ$ ) and freeze-dried. Digestibilities in the digesta samples were calculated relative to the  $\text{Cr}_2\text{O}_3$  marker.

#### *Chemical analysis*

All analyses were carried out in duplicate and results are reported on a dry matter basis. Before analysis, representative feed samples were ground in a Cyclotec 1093 sample mill (Tecator AB, Höganäs, Sweden) to pass a 0.5 mm screen. Samples of freeze-dried digesta were ground in a Retsch mill (0.5 mm screen size). Dry matter was determined by oven drying at  $105^\circ$  for 16 h. Ash and crude protein ( $\text{N} \times 6.25$ ) were analysed according to standard methods of the Association of Official Analytical Chemists (1984). Crude fat was extracted with diethyl ether in a Tecator Soxtec System HT after 3 M-HCl acid-hydrolysis (Anon, 1971). Starch was determined enzymically (Åman & Hesselman, 1984). Total dietary fibre, defined as the sum of non-starch polysaccharides and Klason lignin was analysed according to the method of Theander & Westerlund (1986).  $\text{Cr}_2\text{O}_3$  was determined as described by Fenton & Fenton (1979). Caecal samples were extracted in 50 mM-Tris-HCl buffer (pH 6.5) to a sample concentration of 1 mg/ml and analysis of caecal SCFA was performed by HPLC. A filtrate (20  $\mu\text{l}$ ) of the sample medium was injected onto a Biorad Amnax HPX-87H column at  $60^\circ$  with a flow-rate of 0.4 ml eluent (0.05 M- $\text{H}_2\text{SO}_4$ )/min, and the refractive index was measured using a Tecator RI 5902 refractometer (Kjell Larsson, personal communication).

Plasma was isolated from blood samples by centrifugation (200 g) and triacylglycerol, total cholesterol and high-density lipoprotein (HDL) concentrations were analysed using enzymic colorimetric kits (Boehringer Mannheim Diagnostica).

#### *Calculations and statistical analysis*

Statistical analysis of the registered variables (production results, plasma triacylglycerol and cholesterol concentrations, and ileal digestibility values) was performed by an analysis of variance procedure, the general linear model (GLM) supported by the statistical analysis system (Statistical Analysis Systems Institute Inc., 1985). In the statistical model, the main effects of diet (individual diets; *ad lib.*-fed C and BP, C-1, C-3, BP-1 and BP-3), feeding regimen (*ad lib.* or restricted), class of diet (C or BP-diet) and time (bird age or time after feeding) were considered. The effect of sex was not considered when analysing production variables since these results are presented as cage means and live weights were not influenced by the effect of sex.

## RESULTS

### *Diets*

The content of starch accounted for 520 g/kg dry matter of the C diet while the content in the BP diet was approximately 480 g/kg (Table 2). The contents of crude protein, crude fat

Table 2. *Chemical composition (g/kg dry matter) of the control and sugar-beet-pulp-containing broiler chicken diets*

	Control diet	Sugar-beet-pulp-containing diet
Starch	522.0	483.6
Crude protein	182.8	186.4
Crude fat (HCl)	55.6	54.1
Ash	72.7	76.6
Non-starch polysaccharide residues		
Arabinose	12.3	20.2
Xylose	16.2	15.6
Glucose	42.4	41.0
Uronic acids	15.9	28.3
Klason lignin	7.0	7.0
Total dietary fibre	115.7	138.6

and ash were similar between the C and BP diets. The sum of non-starch polysaccharide residues accounted for approximately 120 and 140 g/kg dry matter content of the C and BP diets respectively and the predominant non-starch polysaccharide residues were arabinose, xylose, glucose and uronic acids. Levels of arabinose and uronic acid residues in the BP diet were 1.6 and 1.8 times greater respectively than in the C diet.

#### *Production study*

The mortality for the entire experiment was 1% and was not significantly influenced by individual diet, feeding regimen, class of diet or bird age.

Over the whole experimental period, broiler chicken live weights and feed intakes were significantly influenced by feeding regimen ( $P < 0.05$ ). Feed conversion ratio was affected by both diet and feeding regimen ( $P = 0.001$ ).

Restricted feeding reduced body weight on days 13 and 20 (Table 3). Improved feed conversion ratios were generally observed amongst chickens given the restricted diets compared with chickens given the *ad lib.* diets.

#### *Plasma lipid study*

Plasma triacylglycerol concentrations were influenced ( $P = 0.001$ ) by individual diet and feeding regimen and bird age. Total plasma cholesterol concentrations were influenced by diet, feeding regimen and class of diet ( $P = 0.001$ ) while plasma HDL concentrations were affected ( $P = 0.001$ ) by diet and feeding regimen.

Triacylglycerol concentrations were generally higher at day 14 in comparison with those observed at day 21. In general, decreasing feed frequency of the restricted diets increased plasma lipid concentrations compared with the *ad lib.*-fed diets in their respective dietary classes (Table 4). The greatest concentrations of plasma lipids were observed amongst chickens given the C-1 and BP-1 restricted diets. It is also noteworthy that *ad lib.* feeding of the BP diet resulted in the lowest plasma triacylglycerol concentrations.

At day 14, increased plasma triacylglycerol concentrations were observed amongst chickens given the C-1 and BP-1 diets in comparison with those of birds given the *ad lib.* diets. *Ad lib.* feeding of the BP diet significantly reduced total plasma cholesterol concentrations compared with the BP-1 diet as well as all control diets. In addition, on day 14, plasma HDL-cholesterol concentrations amongst chickens given the *ad lib.* BP diet

Table 3. *Live weight, cumulative feed intake and feed conversion ratio of broiler chickens receiving control (C) or sugar-beet-pulp-containing (BP) diets\**

(Means for sixty-four chickens)

Diet ...	C			BP			Pooled SEM
	Restricted†			Restricted†			
	<i>ad lib.</i>	C-1	C-3	<i>ad lib.</i>	BP-1	BP-3	
Body wt (g)							
Day 13	224 <sup>a</sup>	205 <sup>b</sup>	200 <sup>bc</sup>	208 <sup>ab</sup>	183 <sup>cd</sup>	182 <sup>d</sup>	6.2
Day 20	451 <sup>a</sup>	399 <sup>bd</sup>	394 <sup>bc</sup>	422 <sup>ab</sup>	372 <sup>cd</sup>	366 <sup>c</sup>	11.1
Cumulative feed intake (g)							
Day 13	288 <sup>a</sup>	233 <sup>b</sup>	234 <sup>b</sup>	254 <sup>c</sup>	206 <sup>d</sup>	206 <sup>d</sup>	6.0
Day 20	657 <sup>a</sup>	526 <sup>b</sup>	527 <sup>b</sup>	608 <sup>c</sup>	487 <sup>d</sup>	487 <sup>d</sup>	11.5
Feed conversion ratio (g feed/g wt gain)							
Day 13	1.57 <sup>a</sup>	1.40 <sup>b</sup>	1.44 <sup>b</sup>	1.50 <sup>ab</sup>	1.43 <sup>b</sup>	1.43 <sup>b</sup>	0.041
Day 20	1.60 <sup>a</sup>	1.46 <sup>b</sup>	1.48 <sup>b</sup>	1.59 <sup>a</sup>	1.46 <sup>b</sup>	1.49 <sup>b</sup>	0.032

<sup>a, b, c, d</sup> Mean values within a row with unlike superscript letters were significantly different ( $P < 0.05$ ).

C-1, BP-1, restricted diet given once daily; C-3, BP-3, restricted diet given three times daily.

\* For details of diets and procedures, See Table 1 and pp. 390–391.

† From days 4 to 20 of the experiment the feed restriction corresponded to 0.8 of the feed given to chickens receiving the *ad lib.*-fed diets.

were significantly reduced relative to the birds receiving the C-1, BP-1 and C-3 restricted diets.

On day 21 only the plasma triacylglycerol concentrations of chickens given the C-1 diet were significantly greater than those of chickens given other diets, and chickens fed on the *ad lib.* C diet had significantly reduced total plasma cholesterol concentrations relative to those birds receiving the C-1 and C-3 restricted diets. Restricted feeding of the C-1 diet at day 21 resulted in significantly increased plasma HDL-cholesterol concentrations compared with concentrations amongst chickens fed on the *ad lib.* C diet but not the C-3 restricted diet. Chickens given the *ad lib.* BP diet had significantly reduced ( $P < 0.05$ ) plasma HDL-cholesterol concentrations compared with chickens receiving both restricted C and BP diets, although not in comparison with those chickens given the *ad lib.* C diet.

#### *Postprandial plasma triacylglycerol study*

Feed intakes for the 1 h feeding period were on average 8.3 (range 7.7–8.9) g feed per chicken for chickens fed on the C, C-1, BP and BP-1 diets and no significant differences in feed intake between diets were observed. Plasma triacylglycerol concentration during the triacylglycerol response study was influenced by time-period after feeding ( $P = 0.008$ ) and class of diet ( $P = 0.05$ ).

Chickens fed on control diets before the triacylglycerol response study were observed to have increased plasma triacylglycerol concentrations immediately after feed was removed 1 h after feeding commenced (Table 5) in comparison with chickens fed on BP diets. The greatest plasma triacylglycerol concentrations for chickens given the BP diet *ad lib.* and BP-1 restricted diets were observed at 2 and 3 h after feed was given respectively. The greatest postprandial triacylglycerol response was observed amongst chickens given the C-1 restricted diet 2 h after feeding and plasma triacylglycerol concentrations were significantly elevated at 1 and 2 h after feed provision in comparison with chickens given other types of diet. The greatest plasma triacylglycerol concentration amongst chickens previously



Table 4. Plasma triacylglycerol, total plasma cholesterol concentrations, high-density-lipoprotein (HDL)-cholesterol and HDL:total plasma cholesterol ratio of broiler chickens receiving control (C) or sugar-beet-pulp-containing (BP) diets\*

(Means for eight chickens)

Diet ...	C			BP			Pooled SEM
	<i>ad lib.</i>	Restricted†		<i>ad lib.</i>	Restricted†		
		C-1	C-3		BP-1	BP-3	
<b>Day 14</b>							
Triacylglycerols (mM)	0.45 <sup>a</sup>	1.69 <sup>c</sup>	1.05 <sup>b</sup>	0.35 <sup>a</sup>	1.40 <sup>bc</sup>	1.04 <sup>b</sup>	0.177
Plasma cholesterol (mM)							
Total	5.72 <sup>a</sup>	6.52 <sup>a</sup>	6.14 <sup>a</sup>	3.89 <sup>b</sup>	6.42 <sup>a</sup>	5.20 <sup>ab</sup>	0.479
HDL	2.75 <sup>ab</sup>	3.21 <sup>a</sup>	3.07 <sup>a</sup>	2.47 <sup>b</sup>	3.16 <sup>a</sup>	2.82 <sup>ab</sup>	0.210
HDL:total cholesterol	0.53	0.51	0.52	0.64	0.50	0.54	0.047
<b>Day 21</b>							
Triacylglycerols (mM)	0.57 <sup>a</sup>	1.10 <sup>b</sup>	0.52 <sup>a</sup>	0.24 <sup>a</sup>	0.58 <sup>a</sup>	0.43 <sup>a</sup>	0.140
Plasma cholesterol (mM)							
Total	5.31 <sup>a</sup>	6.48 <sup>b</sup>	6.50 <sup>b</sup>	5.34 <sup>a</sup>	6.04 <sup>ab</sup>	5.68 <sup>ab</sup>	0.364
HDL	2.49 <sup>ac</sup>	3.04 <sup>b</sup>	2.95 <sup>ab</sup>	2.31 <sup>c</sup>	2.87 <sup>ab</sup>	2.81 <sup>ab</sup>	0.176
HDL:total cholesterol	0.47	0.48	0.46	0.46	0.47	0.49	0.036

<sup>a, b, c</sup> Mean values within a row with unlike superscript letters were significantly different ( $P < 0.05$ ).

C-1, BP-1, restricted diet given once daily; C-3, BP-3, restricted diet given three times daily.

\* For details of diets and procedures, See Table 1 and pp. 390–392.

† From days 4 to 20 of the experiment the feed restriction corresponded to 0.8 of the feed given to chickens receiving the *ad lib.*-fed diets.

Table 5. Plasma triacylglycerol concentrations (mM) of broiler chickens receiving control (C) or sugar-beet-pulp-containing (BP) diets over a 6 h sampling period after a 3 h fasting period\*

(Means for two chickens)

Diet ...	C		BP		Pooled SEM
	<i>ad lib.</i>	Restricted†	<i>ad lib.</i>	Restricted†	
		C-1		BP-1	
<b>Time interval after feeding (h)</b>					
0‡	0.84	0.70	0.62	0.50	0.149
1	0.46 <sup>a</sup>	2.30 <sup>b</sup>	0.97 <sup>a</sup>	1.23 <sup>a</sup>	0.277
2	1.44 <sup>ab</sup>	1.73 <sup>b</sup>	1.12 <sup>a</sup>	0.96 <sup>a</sup>	0.137
3	0.77 <sup>a</sup>	1.00 <sup>a</sup>	0.86 <sup>a</sup>	1.64 <sup>b</sup>	0.225
4	0.45	0.46	0.44	0.54	0.140
5	0.54	0.42	0.31	0.46	0.125
6	0.81	0.49	0.44	0.32	0.167

<sup>a, b</sup> Mean values within a row with unlike superscript letters were significantly different ( $P < 0.05$ ).

C-1, BP-1, restricted diet given once daily.

\* For details of diets and procedures, see Table 1 and pp. 390–392.

† From days 4 to 20 of the experiment the feed restriction corresponded to 0.8 of the feed given to the chickens receiving the *ad lib.*-fed diets.

‡ Blood sample taken after a 3 h fast.

Table 6. *Digesta dry matter content (g/kg) and apparent ileal digestibility of nutrients and non-starch polysaccharide residues in the last third of the small intestine of broiler chickens receiving control (C) or sugar-beet-pulp-containing (BP) diets\**

(Means for twenty-four chickens)

Diet...	C		BP		Pooled SEM
	<i>ad lib.</i>	Restricted† C-1	<i>ad lib.</i>	Restricted† BP-1	
Digesta dry matter content	225 <sup>a</sup>	235 <sup>b</sup>	188 <sup>c</sup>	184 <sup>c</sup>	2.9
Ileal digestibility					
Crude protein (N × 6.25)	0.79	0.80	0.79	0.80	0.006
Crude fat	0.82	0.84	0.81	0.80	0.011
Starch	0.97 <sup>a</sup>	0.98 <sup>b</sup>	0.96 <sup>c</sup>	0.97 <sup>a</sup>	0.003
Organic matter	0.79 <sup>a</sup>	0.80 <sup>a</sup>	0.73 <sup>b</sup>	0.75 <sup>b</sup>	0.004
Non-starch polysaccharide residues					
Arabinose	-0.06	-0.04	0.02	-0.05	0.034
Xylose	-0.11 <sup>ab</sup>	0.05 <sup>a</sup>	-0.23 <sup>b</sup>	-0.07 <sup>ab</sup>	0.076
Glucose	0.46 <sup>a</sup>	0.48 <sup>a</sup>	0.18 <sup>b</sup>	0.19 <sup>b</sup>	0.066
Uronic acids	0.03	0.05	0.06	0.28	0.130
Total dietary fibre	0.30 <sup>ab</sup>	0.35 <sup>a</sup>	0.15 <sup>c</sup>	0.22 <sup>bc</sup>	0.029

<sup>a, b, c</sup> Mean values within a row with unlike superscript letters were significantly different ( $P < 0.05$ ).

C-1, BP-1, restricted diet given once daily.

\* For details of diets and procedures, see Table 1 and pp. 390–392.

† From days 4 to 20 of the experiment the feed restriction corresponded to 0.8 of the feed given to the chickens receiving the *ad lib.*-fed diets.

receiving the BP-1 restricted diet occurred 3 h after feedings and was significantly elevated in comparison with plasma triacylglycerol concentrations of birds fed the *ad lib.* BP diet as well as chickens given control diets.

#### Digestibility study

The ileal digesta dry matter content was significantly influenced ( $P = 0.001$ ) by diet as well as class of diet. Individual diet and feeding regimen significantly affected ( $P = 0.001$  and  $P = 0.006$  respectively) the ileal digestibility of starch while individual diet and class of diet influenced ( $P < 0.01$ ) ileal organic matter digestibility. The ileal digestibilities of glucose residues and total dietary fibre were both influenced by individual and class of diet ( $P < 0.01$ ).

Chickens given BP diets were observed to have significantly reduced ( $P < 0.05$ ) ileal organic matter digestibility in comparison with chickens receiving control diets (Table 6). BP diets significantly reduced ( $P < 0.05$ ) total dietary fibre digestibility in comparison with that of chickens receiving the C diets. Digesta dry matter content was increased amongst chickens given the C-1 restricted diet in comparison with the *ad lib.*-fed C diet as well as the BP diets, and feeding of BP diets generally reduced ileal dry matter content compared with the C diets. Feeding of BP diets generally reduced ileal digestibility of glucose residues and feeding of the BP-1 restricted diet increased (although not significantly) uronic acid digestibility in comparison with the *ad lib.* BP diet. Chickens fed on the BP-1 restricted diet also had increased ileal total dietary fibre digestibility compared with chickens given the *ad lib.* BP diet.

Generally, numerical although not significant differences in caecal SCFA concentration



Table 7. Short-chain fatty acid content (mg/g dry matter) of caecal digesta from broiler chickens receiving control (C) or sugar-beet-pulp-containing (BP) diets for 25 d\*

Diet ...	C		BP		Pooled SEM
	<i>ad lib.</i>	Restricted† C-1	<i>ad lib.</i>	Restricted† BP-1	
Short-chain fatty acids					
Acetic acid	15.3	18.7	17.2	15.9	1.53
Propionic acid	1.9	4.1	2.5	2.5	1.42
Butyric acid	2.6 <sup>a</sup>	5.4 <sup>b</sup>	3.7 <sup>ab</sup>	4.0 <sup>ab</sup>	0.65

<sup>a, b</sup> Mean values within a row with unlike superscript letters were significantly different ( $P < 0.05$ ).

C-1, BP-1, restricted diet given once daily.

\* For details of diets and procedures, see Table 1 and pp. 390–392.

† From days 4 to 20 of the experiment the feed restriction corresponded to 0.8 of the feed given to the chickens receiving the *ad lib.*-fed diets.

were observed between chickens given the various diets. The greatest caecal SCFA concentrations were observed amongst chickens given the C-1 restricted diet (Table 7). Birds receiving this diet had increased concentrations of acetic and propionic acids in comparison with chickens given other diets, and significantly increased ( $P < 0.05$ ) butyric acid concentrations in comparison with chickens given the *ad lib.* C diet. SCFA concentrations were not significantly different between chickens given the *ad lib.* BP and BP-1 restricted diets, although SCFA concentrations amongst chickens given BP diets were generally increased in comparison with concentrations amongst chickens receiving the *ad lib.* C diet.

#### DISCUSSION

In the present experiment, chickens fed on the *ad lib.* BP diet generally had lower body weights and feed intakes, improved feed conversion ratio, reduced plasma lipid concentrations, reduced postprandial triacylglycerol response and reduced ileal digestibility of organic matter compared with birds fed on the *ad lib.* C diet. Decreasing meal frequency and feed intake of control as well as BP-containing diets generally reduced body weight and feed conversion ratio and elevated plasma lipid concentrations. It is noteworthy that the effects of reduced meal frequency were largely offset by the inclusion of sugar-beet pulp in the diet.

Water-soluble pectins have been shown to delay gastric emptying in rats (Chang, 1983) and humans (Sandhu *et al.* 1987) probably as a result of increased viscosity and distension of the duodenum (Sellers, 1977); the resulting increase in satiety may also account for the reduced feed intake and growth rate of chickens fed on *ad lib.* BP diets in the present experiment. Furthermore, dietary pectins, by virtue of their relatively high water-holding capacity (Michel *et al.* 1988), tend to increase viscosity in the small intestine (Graham *et al.* 1986). The reduced ileal dry matter content of chickens fed on BP diets in this experiment was probably due to the increased water-holding capacity of the pectins. It is possible that viscous fibres act as barriers to diffusion and absorption of nutrients in the small intestine, including dietary fat in the form of micelles (Vahouny & Cassidy, 1986), or that dietary fibres entrap or sequester bile acids and in so doing increase faecal sterol excretion (Furda, 1990). Interruption of enterohepatic circulation increases hepatic bile acid synthesis from cholesterol, thus lowering the pool of plasma low-density lipoprotein (LDL) and total

cholesterol (Lampe *et al.* 1991) which is in agreement with the observed reduction in plasma total cholesterol concentrations amongst chickens fed on the *ad lib.* BP diet in the present study. Plasma triacylglycerol concentrations of chickens receiving the C-1 and BP-1 diets were elevated approximately three-fold in comparison with chickens given the *ad lib.* C and BP diets respectively on day 14. Studies on meal frequency in rats (Fábry & Kujalová, 1960) have shown that animals adapt to periods of reduced meal frequency by gorging feed, which results in enlargement of the gastrointestinal tract. In human studies, an increased postprandial secretion of insulin (Jenkins *et al.* 1989) and increased lipogenesis have been observed and these factors can presumably be related directly to the degree of meal restriction. Insulin mediates lipoprotein lipase (EC 3.1.1.34; LPL) and is consequently associated with enhanced lipoprotein metabolism (O'Looney & Vahouny, 1987). Hydrolysis of triacylglycerol-rich lipoproteins by LPL yields free triacylglycerols which can be taken up by extrahepatic cells (Cryer, 1987). Moreover, LPL hydrolysis of chylomicrons and very-low-density lipoproteins (VLDL) results in the formation of HDL in normal adults, normal children and diabetics (Quinn *et al.* 1982). Elevated triacylglycerol and HDL concentrations on days 14 and 21 of chickens fed on diets once daily in the present experiment may be an indication, therefore, of an adaptive increase in the hydrolysis of triacylglycerol-rich lipoproteins. Additionally, increased postprandial secretion of insulin as a result of gorging may account for increased LPL activity which would be related to increased postprandial plasma triacylglycerol concentrations amongst chickens given diets once daily on day 22.

Certain dietary fibres are understood to have lipid-reducing effects (Furda, 1990). Viscous dietary fibres have been shown to increase the apparent thickness of the unstirred boundary layer *in vitro* (Johnson & Gee, 1981) as well as *in vivo* (Dietschy *et al.* 1971) and impede the rate of glucose uptake from gut sections in man (Flourie *et al.* 1984). Postprandial levels of dietary triacylglycerols of chickens fed on the *ad lib.* BP diet were reduced in comparison with plasma triacylglycerol concentrations amongst chickens fed on the *ad lib.* C diet, indicating that diffusion of triacylglycerols may be impaired by the viscous pectins. It may be assumed, therefore, that micelles or mixed micelles would be subject to similar restrictions of diffusion accounting for the generally reduced postprandial plasma lipid concentrations observed amongst chickens given the *ad lib.* BP diet compared with chickens given the *ad lib.* C diet in the present experiment. Although uptake of lipids may have been restricted by the presence of viscous pectins, there was no significant evidence obtained to suggest that this was caused by a reduced ileal digestibility of crude fat.

The increased postprandial triacylglycerol response by chickens receiving the C-1 restricted diet compared with chickens given the *ad lib.* C diet may indicate a degree of intestinal adaptation. It is noteworthy that chickens given the *ad lib.* BP diet had a reduced plasma triacylglycerol response in comparison with chickens given the *ad lib.* C diet which may be attributed, once more, to enhanced viscosity from the pectins from the BP diet. Plasma triacylglycerol concentrations amongst chickens fed on the BP-1 restricted diet were elevated several hours after feeding suggesting that pectins delayed gastric emptying despite the meal restriction and, therefore, effectively assisted in spreading the nutrient load.

The accumulation of SCFA in the caeca of chickens given the C-1 restricted diet suggests more efficient caecal metabolism of nutrients which may not have been absorbed in the small intestine. If rate of transit through the gastrointestinal tract is increased as a result of intermittent feeding of a high-fibre diet, loss of nutrients may occur before intestinal absorption can take place which may lead, therefore, to enhanced caecal bacterial activity and caecal hypertrophy. Soluble fibres such as mixed-linked  $\beta$ -glucans are fermentable in the human colon (Cummings *et al.* 1987). In the present experiment, increased

concentrations of propionate in caeca of chickens given BP diets in comparison with chickens receiving the *ad lib.* C diet suggested that the relatively indigestible pectins may still be fermented in the caeca.

The nutritional effects of increased meal frequency were indicated in the observed reduction in plasma lipid concentrations and reduced postprandial triacylglycerol concentration. Inclusion of dietary pectins from sugar-beet pulp were concluded to reduce plasma lipid levels beneficially in particular, and inclusion of sugar-beet pulp in the chicken diets may assist in overcoming high plasma lipid concentrations associated with reduced meal frequency. Further work into the effect of meal frequency on insulin and the enzymes mediated by insulin coupled with a better understanding of changes in the gastrointestinal tract are required in determining the mechanisms underlying the hypercholesterolaemic response to gorging.

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