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Effects of increasing levels of sugar-beet pulp in broiler chicken diets on nutrient digestion and serum lipids

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Broiler chickens were fed on a control diet based on maize or on diets including conventionally-dried (standard pulp) or vacuum-dried (Fipec pulp) sugar-beet pulp at inclusion levels of 23, 46 and 92 g/kg. Diets were fed *ad lib.* except for half of the chickens fed on the control diet which were fed twice daily at a restricted level. Although not statistically significant, chickens given the 23 g sugar-beet pulp/kg diets generally consumed more feed, had increased body weights and converted feed more efficiently at both day 14 and 21 than those fed on the control diet or diets including 46 or 92 g sugar-beet pulp/kg. Ileal digestibilities of organic matter, crude fat and crude protein generally decreased with increasing levels of sugar-beet pulp in the diet. Birds fed on diets including sugar-beet pulp had reduced total serum cholesterol concentrations. There were only minor differences obtained in production responses, serum cholesterol concentrations, digestibilities and carcass composition between chickens fed on the two types of beet pulp, indicating that the different drying procedures had very little influence on the product. High triacylglycerol and total serum cholesterol concentrations obtained for the restricted level-fed chickens demonstrated a meal frequency factor.

Sugar beet pulp: Serum lipids: Serum cholesterol: Dietary fibre: Meal frequency: Chickens

It is well established that certain factors increase the risk of cardiovascular disease in man; hypercholesterolemia and hypertriacylglycerolaemia are considered major risk factors and are at the forefront of research efforts (Anderson *et al.* 1990).

In recent years extensive investigations into the effect of dietary fibres on lipid metabolism have been performed (Anderson *et al.* 1990; Furda, 1990). Different types of dietary fibre have different lipid-altering properties. Oats and barley fibres have cholesterol-lowering effects (Prentice *et al.* 1982; Gold & Davidson, 1988), believed mainly to be a result of the high content of soluble $(1 \rightarrow 3), (1 \rightarrow 4)$ mixed-linked β-glucans in endosperm cell walls of these cereals (Newman *et al.* 1989).

Numerous theories have been proposed concerning the mechanisms by which dietary fibres interact with dietary lipids. However, all of these theories have limitations, mainly as a result of the great chemical diversity of dietary fibres and difficulties in the measurement of reactions occurring in the body and small intestine (Furda, 1990). The theory receiving the greatest attention is that dietary fibres increase bile acid and neutral sterol excretion and in so doing prevent resorption by binding or absorbing these sterols (Anderson & Tietyen-Clark, 1986). The fundamental problem with this theory is that there is no basis for chemical binding of bile acids to dietary fibres (Furda, 1990) although physical entrapment of lipids by dietary fibres may be possible. Alternatively, soluble dietary fibres (e.g. pectins) may inhibit lipid absorption by increasing digesta viscosity (Johnson & Gee, 1981).

Dried sugar-beet pulp which has a high dietary fibre content and is rich in pectins has been shown to increase faecal bile acid excretion in rats (Gallaher *et al.* 1992). The dried beet pulp can be obtained by direct heating in a drum dryer or by a vacuum drying procedure at low temperature. It is known from baking experiments that high temperatures may cause considerable chemical alterations, such as the formation of Maillard products and increased solubilization of fibre polysaccharides (Westerlund *et al.* 1988).

The present experiment was conducted in order to study the effects on production results, ileal digestibility, serum cholesterol concentration and carcass composition in broiler chickens fed a low-fibre diet supplemented with increasing levels of a standard-dried or vacuum-dried sugar-beet pulp. It has been argued that fibre products indirectly lower serum cholesterol concentrations by replacing dietary fat and energy (Swain *et al.* 1990). In order to study this possible effect the low-fibre diet was fed both *ad lib.* and also at a restricted level.

MATERIALS AND METHODS

Sugar-beet pulp

Standard high-temperature-dried sugar-beet pulp (standard pulp) and low-temperature–vacuum-dried sugar-beet pulp (Fipec pulp) were supplied by the Swedish Sugar Company, Arlöv, Sweden.

Diets

The chickens received a control diet based on 405 g maize and 246 g maize starch/ kg, or iso-nitrogenous and iso-energetic diets in which part of the maize starch, fish meal, meat-and-bone meal and animal fat components were substituted with standard pulp or Fipec pulp at inclusion levels of 23, 46 or 92 g/kg of the feed (Table 1). Lysine and DL-methionine were included at a level of 10 g/kg in each of the mash diets, and the diets were milled to pass a 3·5 mm screen. On a dry matter basis the beet pulp diets were calculated to have an average metabolizable energy (ME) content of 13·6 MJ/kg (range 13·1–13·8 MJ/kg), while the control diet was calculated to have an ME content which was approximately 4% higher.

Chickens

A total of 288 1-d-old broiler chickens (Ross; Kronfågel AB, Väderstad, Sweden) of mixed sex were divided into twenty-four groups of twelve chickens with an average group weight of 496 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 eight experimental diets were randomly assigned to three replicates (cages) each. Chickens were wing-banded and their sex determined on day 2 of the experiment. All beet pulp diets and three of the control replicates were fed on an *ad lib.* basis. Chickens fed on these diets had free access to food and water except for 3 h before sera collection, during which time only water was provided. In order to display the effects of differences in energy intake, strict rationing was imposed upon the chickens in the remaining three cages given the control diet. On days 1–7 the chickens fed on this restricted diet were given 90% of the average total feed intake of the chickens given the *ad lib.*-fed control diet. From day 7 until the end of the production experiment on day 22, the chickens given the restricted control diet were fed 85% of the mean feed intake of the chickens provided with the *ad lib.*-fed control diet. The restricted diet was fed twice daily (08·30 and 16·30 hours) and chickens consumed their feed within approximately 2·5 h.

Production study

Individual chicken weights and group cumulative feed intake (air-dry weight) were recorded at 14 and 21 d of age and group feed conversion ratios were calculated on a weight-gain basis (g cumulative feed intake/g weight gain).

Table 1. *Composition of the broiler chicken diets (g/kg air-dry basis) containing increasing levels of conventionally-dried (Standard) or vacuum-dried (Fipec) sugar-beet pulp**

Type of diet...	Control		Standard pulp (g/kg)			Fipec pulp (g/kg)		
Ingredient	*Ad. lib.*	Restricted†	23	46	92	23	46	92
Maize	405·0	405·0	405·0	405·0	405·0	405·0	405·0	405·0
Soya-bean meal	200·0	200·0	200·0	200·0	200·0	200·0	200·0	200·0
Fish meal	40·5	40·5	39·0	37·8	35·0	39·0	37·8	35·0
Meat-and-bone meal	40·5	40·5	39·0	37·8	35·0	39·0	37·8	35·0
Animal fat	18·8	18·8	18·7	18·7	19·0	18·7	18·7	19·0
Sugar-beet pulp	—	—	23·0	46·0	92·0	23·0	46·0	92·0
Maize starch	246·2	246·2	228·3	207·7	167·0	228·3	207·7	167·0
Limestone	17·0	17·0	17·0	17·0	17·0	17·0	17·0	17·0
Mono-calcium phosphate	13·0	13·0	13·0	13·0	13·0	13·0	13·0	13·0
Vitamin and trace element premix	10·0	10·0	10·0	10·0	10·0	10·0	10·0	10·0
Salt	3·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0
Cholesterol	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0
Lysine-hydrochloride	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0
DL-methionine	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0

* For details of procedures, see p. 128.
† Given twice daily at a restricted level.

Digestibility study

From day 18 until day 23 of the experiment chickens were fed on diets containing Cr_2O_3 incorporated at a level of 4 g/kg (fresh-weight basis). On day 23 of the experiment four randomly-selected chickens from each cage (twelve from each treatment) were killed (gassed with CO_2) and their gastrointestinal tracts were quickly removed. The contents of the last third of the small intestine (denoted ileum) of the chickens were collected separately, pooled for each group, frozen (−25°) and freeze-dried. Digestibilities in the digesta samples were calculated relative to the Cr_2O_3 marker.

Serum triacylglycerols and cholesterol

At both days 15 and 22, chickens were starved for 3 h after which two birds (one male and one female) from each cage, 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 triacylglycerol and cholesterol analysis.

Chemical analysis

All analyses were carried out in duplicate and are reported on a dry matter basis. Prior to analysis, representative feed samples were ground in a Tecator cyclone mill to pass a 0·5 mm screen. Samples of freeze-dried digesta were ground in a Retsch mill with a 0·5 mm screen size.

Dry matter was determined by oven-drying at 105° for 16 h. Ash and crude protein (N × 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 Theander & Westerlund (1986). Cr_2O_3 was determined according to Fenton & Fenton (1979).

Serum was isolated from coagulated blood samples by decanting, and triacylglycerol, total cholesterol and high density lipoprotein (HDL) concentrations were analysed using enzymic colorimetric kits (Boehringer Mannheim Diagnostica).

Carcass composition

The three male birds of the six animals from each treatment slaughtered for blood analysis were selected for analysis of carcass composition. Carcasses were obtained by removing head, legs below the tibio-tarsal joint, feathers and gastro-intestinal tract from the slaughtered body. Carcasses were ground in a meat mincer and subsequently freeze-dried. Samples were analysed for crude protein, crude fat and ash content according to the methods described.

Calculations and statistical analysis

The production results were analysed by analysis of covariance, using the general linear model (GLM) supported by the statistical analysis system (SAS Institute Inc., 1985), and taking into account the effect of diet as main effect and adjusting treatment means for differences in the male:female ratio in each treatment. Statistical analysis of the other registered variables (serum triacylglycerol and cholesterol concentrations, ileal digestibility values and carcass composition) were done by analysis of variance also using the GLM-procedure. In these analyses the main effects of type of diet, sex and age were considered, while the effect of feeding regimen (*ad lib.* or restricted) was tested by contrasts (also provided by the GLM procedure) between the two control diets. Effect of sex and age was not considered when analysing digestibility variables, since digesta samples were pooled and only collected on one occasion (day 23) and sex was not included in the model when analysing carcass composition since only male broilers were selected. All registered variables are presented as least squared means, which in the case of digestibility values, serum lipids and carcass composition are identical to arithmetic means since these values were unadjusted and also without missing values.

RESULTS

Beet pulp and diets

The composition of the two sugar-beet pulps was very similar; the Fipec pulp had a higher crude fat and a lower dietary fibre content compared to the standard pulp (Table 2). The sum of non-starch polysaccharide residues accounted for 650 g/kg and 620 g/kg of the dry matter content of the standard and Fipec pulps, respectively, and arabinose, xylose, glucose and uronic acids were the predominant non-starch polysaccharide residues. The majority of these residues occurred in an insoluble form, which accounted for more than 80% of the total content of non-starch polysaccharide residues in both pulps.

The content of starch varied between 450–520 g/kg diet whereas the content of ash was about 70 g/kg, crude protein approximately 190 g/kg and crude fat about 60 g/kg (Table 3). The sum of these constituents and the non-starch polysaccharide residues amounted to 98% of the dry matter content of the diets. Relative to the control diet, the content of non-starch polysaccharide residues in the beet pulp diets were, on average, 30, 42 and 85% higher for the 23, 46 and 92 g/kg sugar-beet pulp inclusion levels, respectively.

Production results

The mortality for the experiment was 6% and was not significantly influenced by type of diet or feeding regimen. However, the elevated mortality was a result of an unusually high death rate (50%) in one of the cages allocated to the *ad lib.*-fed control diet. Generally, for the whole experimental period, broiler chicken live weights, feed intakes and feed

Table 2. *Chemical composition (g/kg dry matter) of conventionally-dried (Standard) and vacuum-dried (Fipec) sugar-beet pulp**

	Standard beet pulp	Fipec beet pulp
Starch	Traces	Traces
Crude protein	96·0	96·4
Crude fat	9·8	12·8
Ash	52·5	49·0
Non-starch polysaccharide residues		
Soluble:		
Arabinose	22·0	33·9
Xylose	5·0	1·7
Glucose	2·0	2·5
Insoluble:		
Arabinose	142·0	116·0
Xylose	14·0	14·0
Glucose	176·0	174·0
Uronic acids	218·1	216·5
Klason lignin	11·0	13·0
Dietary fibre	656·1	632·5

* For details of diets and procedures, see p. 129 and Table 1.

Table 3. *Chemical composition (g/kg dry matter) of the broiler chicken diets containing increasing levels of conventionally- (Standard) or vacuum-dried (Fipec) sugar-beet pulp**

Type of diet...	Control		Standard pulp (g/kg)			Fipec pulp (g/kg)		
	Ad. lib.	Restricted†	23	46	92	23	46	92
Starch	522·1	522·1	503·0	497·2	454·0	506·4	495·7	454·7
Crude protein	192·5	192·5	193·4	190·5	195·5	193·3	195·3	193·5
Crude fat	59·2	59·2	57·1	59·1	60·8	56·1	59·1	58·4
Ash	73·2	73·2	68·7	70·1	71·9	67·7	69·6	71·3
Non-starch polysaccharide residues								
Soluble:								
Arabinose	0·8	0·8	1·4	2·1	3·0	1·2	2·5	4·2
Xylose	0·5	0·5	0·5	0·6	0·5	0·5	0·6	0·6
Glucose	0·7	0·7	0·9	1·3	0·8	1·5	0·9	1·0
Insoluble:								
Arabinose	10·4	10·4	14·7	16·9	27·9	14·3	16·2	21·7
Xylose	11·7	11·7	12·5	12·4	14·8	13·7	12·7	13·3
Glucose	19·7	19·7	24·7	26·4	37·7	27·1	28·0	39·0
Uronic acids	11·0	11·0	16·0	22·0	31·0	14·0	20·0	30·0
Klason lignin	3·5	3·5	3·6	3·2	5·5	3·5	3·6	4·3
Dietary fibre	72·0	72·0	93·6	102·2	131·7	93·2	102·4	134·5

* For details of diets and procedures, see p. 129 and Tables 1 and 2.
† Given twice daily at a restricted evel.

conversion ratios were not significantly influenced by type of diet and feeding regimen (*ad lib. v.* restricted). However, chickens receiving diets containing the 23 g/kg inclusion levels of both types of beet pulp generally had the highest body weights and feed intakes and the best feed conversion ratios on both days 14 and 21 (Table 4). At day 21 these chickens also had significantly greater body weights ($P < 0.05$) in comparison with birds fed on the restricted control diet. Chickens fed on the 92 g/kg inclusion levels of both types of beet pulp had live weights, feed intakes and feed conversion ratios that were similar to those of birds fed on the two control diets.

Digestibility study

The ileal dry matter content was significantly influenced by type of diet ($P < 0.01$). There was also an effect of type of diet ($P < 0.05$) on the ileal digestibility of crude fat and organic matter. Crude protein and starch digestibilities, however, did not differ between birds fed on the control diets and those fed on the beet pulp diets.

Digesta dry matter content and ileal digestibilities of organic matter and crude fat were in general reduced with increasing dietary inclusion of beet pulp (Table 5). There were no significant differences in organic matter digestibility between either control diet and the diet containing 23 g Fipec pulp/kg. The digestibility of organic matter was, however, reduced ($P < 0.05$) by the 46 and 92 g/kg inclusion levels of sugar-beet pulp compared with the controls. Chickens fed on diets containing 23 g/kg standard or Fipec pulps had crude fat digestibilities close to levels observed for the control diets, while the 92 g/kg inclusion level of standard pulp reduced crude fat digestibility by 16·5%.

Serum triacylglycerols and cholesterol

Serum triacylglycerols were influenced by type of diet ($P < 0.01$), age ($P < 0.05$) and feeding regimen ($P < 0.01$). Total serum cholesterol concentrations were influenced by type of diet and age ($P < 0.01$) and serum HDL concentrations by diet ($P < 0.05$), age ($P < 0.01$) and feeding regimen ($P < 0.05$).

An overall reduction in total serum cholesterol concentration was observed with increasing beet pulp inclusion levels (Table 6). At both days 15 and 22, serum triacylglycerol concentrations of chickens fed on the restricted control diet were significantly elevated compared with the *ad lib.*-fed control diet and all dietary inclusion levels of the beet pulp. Inclusion of 92 g standard pulp/kg significantly reduced total serum cholesterol concentration compared with the control diets at both days 15 and 22, while at day 22 both the 46 g/kg and 92 g/kg inclusion levels of standard and Fipec pulps reduced ($P < 0.05$) total serum cholesterol levels compared with the *ad lib.*-fed control diet. Total serum cholesterol concentrations were also significantly reduced at both days 15 and 22 for chickens receiving the 46 g/kg and 92 g/kg inclusion levels of Fipec pulp compared with those fed the restricted control diet.

At day 15 the 92 g/kg inclusion level of standard pulp significantly reduced the HDL concentration by 17% compared with the restricted control diet, and no other significant reductions were observed for chickens fed any inclusion level of both beet pulp types and either control diet (Table 6). At day 22 the chickens given the 23 g/kg and 92 g/kg inclusion levels of standard pulp as well as the 46 g/kg and 92 g/kg inclusion levels of Fipec pulp had significantly reduced ($P < 0.05$) HDL concentrations relative to those fed the restricted control, which displayed the highest HDL concentrations.

Carcass composition

Type of diet significantly ($P < 0.05$) affected ash content in the carcasses of broiler chickens.

As a result of increasing beet pulp inclusion the carcass crude fat concentration decreased, although not significantly, while crude protein content increased (Table 7). A similar tendency of increasing ash content with increasing beet pulp inclusion was also apparent, although carcass ash contents of chickens fed on the beet pulp diets were generally lower than those of chickens fed on both the control diets.

Table 4. *Live weights, cumulative feed intakes and feed conversion ratios of broiler chickens receiving diets containing increasing levels of conventionally-dried (Standard) or vacuum-dried (Fipec) sugar-beet pulp**

Type of diet...	Control		Standard pulp (g/kg)			Fipec pulp (g/kg)			
	Ad. lib.	Restricted†	23	46	92	23	46	92	Pooled SEM
Body wt (g):									
Day 14	218	203	245	223	210	247	232	203	16·1
Day 21	451^{ac}	368^{b}	484^{ac}	442^{ac}	408^{bc}	483^{a}	438^{ab}	417^{ab}	24·5
Cumulative feed intake (g):									
Day 14	322^{ab}	285^{b}	331^{ab}	308^{ab}	298^{ab}	339^{a}	321^{ab}	293^{ab}	18·1
Day 21	715^{ab}	619^{b}	755^{a}	711^{ab}	685^{ab}	762^{a}	705^{ab}	659^{ab}	38·9
Feed conversion ratio (g feed/g wt gain):									
Day 14	$1{\cdot}80^{a}$	$1{\cdot}74^{ab}$	$1{\cdot}61^{b}$	$1{\cdot}67^{ab}$	$1{\cdot}74^{ab}$	$1{\cdot}63^{ab}$	$1{\cdot}66^{ab}$	$1{\cdot}79^{ab}$	0·075
Day 21	$1{\cdot}79^{ac}$	$1{\cdot}88^{b}$	$1{\cdot}70^{ac}$	$1{\cdot}77^{ab}$	$1{\cdot}86^{bc}$	$1{\cdot}71^{ac}$	$1{\cdot}76^{ab}$	$1{\cdot}74^{ab}$	0·046

a,b,c Means within a row with unlike superscripts were significantly different ($P < 0{\cdot}05$).
* For details of diets and procedures, see p. 128 and Tables 1–3.
† Given twice daily at a restricted level.

Table 5. *Ileal digesta dry matter content (mg dry matter/g digesta) and apparent ileal digestibility of nutrients in the last third of the small intestine of chickens receiving diets containing increasing levels of conventionally-dried (Standard) or vacuum-dried (Fipec) sugar-beet pulp**

Type of diet...	Control		Standard pulp (g/kg)			Fipec pulp (g/kg)			
	Ad. lib.	Restricted†	23	46	92	23	46	92	Pooled SEM
Ileal digesta dry matter content	205^{a}	204^{a}	200^{a}	190^{a}	171^{bc}	197^{a}	188^{ac}	170^{b}	5·9
Ileal digestibility:									
Crude protein	$0{\cdot}68^{ab}$	$0{\cdot}73^{ab}$	$0{\cdot}71^{ab}$	$0{\cdot}70^{ab}$	$0{\cdot}67^{a}$	$0{\cdot}76^{b}$	$0{\cdot}73^{ab}$	$0{\cdot}71^{ab}$	0·026
Crude fat	$0{\cdot}68^{a}$	$0{\cdot}66^{a}$	$0{\cdot}64^{a}$	$0{\cdot}62^{ab}$	$0{\cdot}56^{b}$	$0{\cdot}65^{a}$	$0{\cdot}64^{a}$	$0{\cdot}63^{a}$	0·022
Starch	0·99	0·99	0·96	0·98	0·97	0·97	0·97	0·98	0·099
Organic matter	$0{\cdot}75^{ae}$	$0{\cdot}76^{a}$	$0{\cdot}73^{be}$	$0{\cdot}71^{bd}$	$0{\cdot}64^{c}$	$0{\cdot}74^{ae}$	$0{\cdot}71^{bd}$	$0{\cdot}68^{d}$	0·011

a,b,c,d,e Means within a row with unlike superscripts were significantly different ($P < 0{\cdot}05$).
* For details of diets and procedures, see p. 129 and Tables 1–3.
† Given twice daily at a restricted level.

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Table 6. *Serum triacylglycerols (mmol/l), total serum cholesterol (Total) and serum high-density lipoprotein (HDL) cholesterol concentrations (mmol/l) at days 15 and 22 of broiler chickens receiving diets containing increasing levels of conventionally-dried (Standard) or vacuum-dried (Fipec) sugar-beet pulp**

Type of diet…	Control		Standard pulp (g/kg)			Fipec pulp (g/kg)			
	Ad. lib.	Restricted†	23	46	92	23	46	92	Pooled SEM
Day 15									
Triacylglycerols	0·44^{a}	1·45^{b}	0·41^{a}	0·54^{a}	0·52^{a}	0·50^{a}	0·49^{a}	0·54^{a}	0·091
Serum cholesterol:									
Total	4·67^{ab}	5·26^{b}	4·28^{ac}	4·21^{ac}	3·71^{c}	4·42^{a}	4·40^{ac}	4·18^{ac}	0·242
HDL	2·53^{ab}	2·83^{a}	2·51^{ab}	2·52^{ab}	2·34^{b}	2·61^{ab}	2·53^{ab}	2·48^{ab}	0·151
Day 22									
Triacylglycerols	0·55^{a}	1·89^{b}	0·49^{a}	0·52^{a}	0·54^{a}	0·60^{a}	0·59^{a}	0·50^{a}	0·097
Serum cholesterol:									
Total	5·52^{a}	5·21^{ab}	5·00^{abd}	4·77^{bc}	4·29^{c}	5·07^{ab}	4·30^{cd}	4·35^{cd}	0·247
HDL	3·16^{ab}	3·53^{a}	3·00^{b}	3·09^{ab}	3·03^{b}	3·17^{ac}	2·78^{bc}	2·96^{bc}	0·169

a,b,c,d Means within a row with unlike superscripts were significantly different ($P < 0·05$).
* For details of diets and procedures, see p. 130 and Tables 1–3.
† Given twice daily at a restricted level.

Table 7. *Carcass composition (g/kg dry matter) at days 15 and 22 of broiler chickens receiving diets containing increasing levels of conventionally-dried (Standard) or vacuum-dried (Fipec) sugar-beet pulp**

Type of diet…	Control		Standard pulp (g/kg)			Fipec pulp (g/kg)			
	Ad. lib.	Restricted†	23	46	92	23	46	92	Pooled SEM
Day 15:									
Ash	98^{ac}	101^{a}	83^{bc}	93^{bc}	99^{c}	81^{b}	85^{ab}	92^{ab}	5·6
Crude protein	464^{a}	507^{ab}	475^{ab}	477^{ab}	512^{b}	465^{a}	480^{ab}	488^{ab}	17·8
Crude fat	404	384	409	405	378	417	401	393	13·5
Day 22:									
Ash	79^{a}	99^{b}	79^{a}	87^{ab}	88^{ab}	82^{ab}	92^{a}	95^{ab}	5·9
Crude protein	469^{a}	484^{ab}	499^{ab}	473^{ab}	499^{ab}	496^{ab}	510^{b}	512^{b}	14·5
Crude fat	419	414	401	400	392	391	373	379	16·1

a,b,c,d Means within a row with unlike superscripts were significantly different ($P < 0·05$).
* For details of diets and procedures, see p. 130 and Tables 1–3.
† Given twice daily at a restricted level.

At day 15, the highest (92 g/kg) inclusion level of standard pulp significantly increased carcass crude protein content compared with that of chickens receiving the *ad lib.*-fed control diet.

At day 22 the chickens given the restricted control diet had an increased ($P < 0.05$) carcass ash content in comparison with those given the *ad lib.*-fed control diet or diets containing 23 g/kg inclusion of standard pulp as well as 46 g/kg inclusion of Fipec pulp. Compared with the *ad lib.*-fed control diet, the 46 g/kg and 92 g/kg inclusion levels of the Fipec pulp also improved the protein retention significantly.

DISCUSSION

The similar results obtained in production results, serum lipid concentrations, digestibilities and carcass composition for chickens fed on the two different types of beet pulp indicate that, in the present study, the drying procedures employed had no significant influence on the physiological properties of the products.

Although not statistically significant, chickens fed on the 23 g/kg inclusion level of beet pulp generally had higher live weights and feed intakes, better feed conversion ratios, higher crude protein digestibilities, lower total serum cholesterol concentrations and higher carcass crude protein contents in comparison with birds receiving the *ad lib.*-fed control diet.

Axelsson & Eriksson (1953) have shown that a dietary crude fibre content of 60–70 g/kg dry matter was required to optimize weight gain and feed conversion ratios in growing pigs. Unfortunately, the crude fibre extracted in these experiments gave a very poor estimate of the actual dietary fibre content since it only represented the most insoluble and lignified components; it is now known that soluble dietary fibres probably exert a much greater influence on metabolism. Chickens usually adapt to fibre-rich diets by increasing the volume of the digestive tract (Håkansson *et al.* 1978) and consequently improve relative feed intake and growth. This was probably one of the factors involved behind the improved production results obtained for birds fed on 23 g/kg inclusion levels. These chickens also displayed a numerically higher carcass crude protein retention in comparison with chickens receiving the *ad lib.*-fed control diet. Moreover, there was a reduced feed intake and growth rate of chickens fed on diets with higher inclusion levels of beet pulp, which could be accounted for by increased satiety due to reduced gastric emptying caused by distension of the duodenum (Sellers, 1977). In pectin-fed rats the digesta were found to be paste-like and the intestines were distended (Luick & Penner, 1991). Pectins derived from beet pulp have also been shown to be soluble in the small intestine of cannulated pigs (Graham *et al.* 1986), thereby possibly creating a viscous environment. However, beet pulp pectin generally has lower gelling power and lower molecular weight in comparison with, for example, apple or citrus pectin (McGinnis & Sequeira, 1982). Furthermore sugar-beet pulp is known to have a high water-holding capacity (Michel *et al.* 1988), which was probably responsible for the decreasing ileal digesta dry matter content of chickens fed on the higher inclusion levels of beet pulp.

In a situation where energy uptake is favoured and protein becomes a limiting factor, chickens may retain the energy surplus as fat, resulting in a fat chicken carcass (Griffiths *et al.* 1977; Jackson *et al.* 1982). In the present experiment birds fed on diets with the lowest inclusion level of beet pulp had the highest feed intakes and crude protein digestibilities; however, only minor differences were obtained in carcass composition between chickens fed on the different treatments. The digestibility values also indicate that, in comparison with the control treatment, protein digestion was not limited by the beet pulp inclusion, while crude fat digestibilities decreased and starch digestibilities were uniformly high. Soluble dietary fibres such as pectins have been shown to decrease the rate of diffusion of glucose in gut sections *in vitro* (Johnson & Gee, 1981) and *in vivo* in man (Flourie *et al.* 1984), and it is likely that lipid micelles also diffuse inefficiently under viscous conditions. Entrapment of bile acids by soluble dietary fibres and consequent inhibition of bile acid resorption (Ebihara & Schneeman, 1989) would also lower serum cholesterol levels and could account for the reduction in total serum cholesterol concentrations in chickens fed on the 92 g beet pulp/kg diets.

Up to day 21 the chickens fed on the restricted diet had an intake of feed and ME which was similar to that of birds fed on the highest level of sugar-beet pulp, but still displayed highly-elevated serum triacylglycerol and cholesterol concentrations. It is noteworthy that serum triacylglycerol concentrations of these chickens were approximately three times greater than those of chickens which received the *ad lib.*-fed control diet. Infrequent feeding has been shown to enlarge the gastrointestinal tract (in order to accommodate large quantities at a single feeding) and to increase lipogenesis in rats (Tepperman & Tepperman, 1965). The high serum triacylglycerol concentrations amongst chickens receiving the restricted control diet might therefore be attributed to a 'gorging' effect as a result of meal infrequency (Fabry & Tepperman, 1970; Jenkins *et al.* 1989). The results obtained highlight the important influence of the many unknown interactions between dietary fibres and other dietary components, and the existence of an optimum level of dietary fibre is indicated.

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