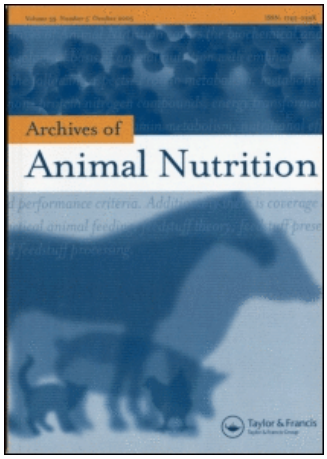

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Effect of graded levels of rapeseed oil in isonitrogenous diets on the development of the gastrointestinal tract, and utilisation of protein, fat and energy in broiler chickens

Henry Jørgensen [a]; Xin Quan Zhao [ab]; Peter Kappel Theil [a]; Kirsten Jakobsen [a]
[a] Department of Animal Health Welfare and Nutrition, Research Centre Foulum, Aarhus University, Tjele, Denmark
[b] Northwest Plateau Institute of Biology, The Chinese Academy of Sciences, Xining, P.R. China

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Effect of graded levels of rapeseed oil in isonitrogenous diets on the development of the gastrointestinal tract, and utilisation of protein, fat and energy in broiler chickens

Henry Jørgensen[a]*, Xin Quan Zhao[a,b], Peter Kappel Theil[a] and Kirsten Jakobsen[a]

[a]*Department of Animal Health, Welfare and Nutrition, Research Centre Foulum, Aarhus University, Tjele, Denmark;* [b]*Northwest Plateau Institute of Biology, The Chinese Academy of Sciences, Xining, P.R. China*

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The effect of feeding 0, 4, 8 and 16% rapeseed oil from 12–42 days of age was studied in broiler chickens on performance, digestibility of nutrients, and development of gastrointestinal tract, protein and energy metabolism. Thirty six female chickens (Ross 208) with initial body weight average 246 g were allocated to the four groups and kept pair-wise in metabolism cages. The chickens were fed similar amounts of metabolisable energy (ME) per day and similar amounts of essential amino acids relative to ME by adjusting with crystalline amino acids. The chickens were subjected to four balance periods each of five days with two 24 h measurements of gas exchange in two open-air-circuit respiration chambers inserted on the second and third day of each period. The addition of rapeseed oil increased the amount of gutfill indicating a reduced rate of passage and causing a hypertrophy of the gastrointestinal tract. There was a positive effect on feed utilisation as well as on digestibility especially of dietary fat together with higher utilisation of protein with addition of rapeseed oil. The partial fat digestibility of rapeseed oil estimated by regression was 91.1% and the partial metabolisability (ME/GE) of the rapeseed oil was estimated to 85% yielding an apparent metabolisable energy value of 34.30 MJ/kg.

Keywords: gutfill; ileal digestibility; heat production; fat digestibility

1. Introduction

Fats and oils are frequently included in broiler diets in order to increase energy density. Several experiments have shown that an increase in energy concentration results in a decrease in feed intake but does not negatively affect daily gain, resulting in an improvement in feed efficiency (Hulan et al. 1984; Nir et al. 1994; Zollitsch et al. 1997). Earlier experiments with growing pigs with either addition of animal fat or rapeseed oil showed that digestible fat improved the efficiency of utilisation of metabolisable energy (ME) substantially (Just 1982; Jørgensen et al. 1996a). However, fat inclusion in broiler diets affects carcass fat quality, because dietary fatty acids can be incorporated directly into body fat (Olomu and Baracos 1991; Scaife et al. 1994; Engberg et al. 1996; Jakobsen 1999; Mlodkowski et al. 2003). Furthermore, the efficiency of utilisation of ME is improved, since the energetic costs of intestinal breakdown, and transport to and synthesis

*Corresponding author. Email: Henry.Jorgensen@agrsci.dk

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within the liver are avoided (Krogdahl 1985). In addition, the absorbed fat or fatty acids can be directly deposited in adipose tissue without any biochemical transformations which makes the efficiency of ME higher than from dietary protein and starch or fibre (Just 1982; Jørgensen et al. 1996a). Nevertheless, fats used in farm animal diets are extremely diverse in chemical structure, which influences their energy value to a great extent (Huyghebaert et al. 1988; Wiseman and Salvador 1989; Nir et al. 1994; Scheele et al. 1999; Zheng et al. 2006; Straarup et al. 2006).

It has been shown that dietary fibre exerts a hypertrophic effect on the visceral organs especially on the gastrointestinal (GI) tract (Hansen et al. 1992; Savory 1992; Jørgensen et al. 1996b). The effect has been ascribed to increased amount of digesta and its viscosity (Simon 1998) which also can be caused by dietary fat (Dänicke et al. 2000). The apparent digestibility of fat and fatty acids is dependent among other factors on chain length of the fatty acids, the ratio between unsaturated and saturated fatty acids, the degree of esterification and the position of fatty acids on the glycerol molecule, as well as dietary factors as crude protein, crude fat and the level of fibre in the diet, and the amount and composition of endogenous fat (Krogdahl 1985; Wiseman and Lessire 1987; Jørgensen et al. 1992b).

The objective of the present study was to determine the effect of increasing dietary levels of rapeseed oil on growth performance, development of the gastrointestinal tract, nutrient digestibility as well as energy and protein retention. Furthermore, ileal digestibility of dry matter and nitrogen was determined at slaughter.

2. Materials and methods

2.1. Animals and diets

A total of 36 female broiler chickens (Ross 208) were kept at 28°C and fed a commercial starter diet from day-old to 12 days of age (in g/kg; wheat, 502; peas, 160; soybean meal, 220; fish meal, 30; DL-methionine, 2; animal fat, 20; vegetable oil, 90 and minerals and vitamins). Then 32 chickens were selected and randomly allocated on four groups in two series. Each group included two extra chickens for substitution if necessary. The animals were placed pair-wise in metabolism cages in an air-conditioned room at 24°C in the first two weeks and at 22°C in the last two weeks. Relative humidity was 60–65% and a 24 h light regimen was maintained.

The diets given in meal form were based on wheat and soybean meal with graded levels of rapeseed oil of 0, 4, 8 and 16% (groups 1, 2, 3 and 4, respectively) from 12–42 days of age (Table 1). The rapeseed oil was double low (fat, 999 g/kg; GE, 40.35 MJ/kg) and was provided by Aarhus Olie A/S (Aarhus, Denmark). All diets were adjusted to about the same digestible protein level by addition of fishmeal, lysine and methionine. In the last balance period 0.2% chromic oxide was added to the diet as a marker for determination of ileal digestibility of dry matter and protein at slaughter.

2.2. Housing and measurement

Four balance periods of five days were performed with 2 d in between during which no collection of excreta took place. The chickens were fed similar amounts of ME per day. The feed allowance of the chickens of the four groups was 100%, 92.5%, 86.2% and 75.7%, respectively, where the daily feed intake of the first group was kept as close to *ad libitum* feed intake as possible. Water was available at all times. Weekly feed consumption was recorded, and the droppings were collected daily from each cage of two birds and

Table 1. Dietary ingredients and chemical composition of the experimental diets.

	Dietary rapeseed oil [%]			
	0	4	8	16
Ingredients [g/kg]				
Rapeseed oil	0	40.0	80.0	160.0
Wheat	654.2	589.5	519.0	382.0
Pea	150.0	150.0	150.0	150.0
Soybean meal, dehulled toasted	146.9	166.0	190.9	238.6
Fishmeal	17.8	20.1	23.1	28.9
Calcium carbonate	12.0	13.0	14.0	15.0
Dicalcium phosphate	9.0	10.0	11.0	12.0
Sodium chloride	2.0	2.0	2.0	2.0
Sodium bicarbonate	2.0	2.0	2.0	2.0
DL-methionine (40%)	3.1	3.5	4.0	5.0
L-lysine (40%)	–	0.9	1.0	1.5
Choline chloride (50%)	0.4	0.4	0.4	0.4
Vitamin and mineral mixture*	2.6	2.6	2.6	2.6
Composition [g/kg DM]				
Protein	223	242	233	260
HCl-fat	28	71	114	179
Starch	504	453	396	321
Sugar	64	64	59	61
Ash	49	55	57	61
Gross energy [MJ/kg DM]	18.33	19.28	20.19	21.52
Fatty acids [g/100g HCl-fat]				
C8:0	0.2	0.1	0.1	0.1
C10:0	0.2	–	0.1	0.1
C12:0	0.2	0.1	0.1	0.1
C14:0	0.3	0.2	0.2	0.1
C16:0	15.4	8.4	7.0	5.7
C16:1	0.4	0.3	0.2	0.2
C18:0	1.6	1.5	1.5	1.5
C18:1n-9	12.5	38.1	44.4	45.8
C18:2n-6	42.9	28.2	24.7	21.3
C18:3n-3	4.4	7.0	8.0	8.1
C20:0	0.1	0.4	0.4	0.4
C20:1n-9	0.7	1.0	1.1	1.1
Sum fatty acids% HCl-fat	78.9	85.3	87.8	84.5

Notes: *Supplying per kg of diet: retinal acetate, 4.3 mg; cholecalciferol, 67 μg; dl-α-tocopheryl, 31 mg; menadione, 2.6 mg; thiamine, 1.0 mg; rioflavin, 8.9; pyridoxine, 3.1mg; d-pantothenic acid, 14.4 mg; niacin, 41.4 mg; betaine anhydrate, 189 mg; folic acid, 1.6 mg; biotin, 104 μg; cyanocobalamin, 21 μg; buthylhydroxytoluen (BHT), 104 mg; Fe as $FeSO_4 \cdot H_2O$, 82.9 mg; Zn as ZnO, 82.8 mg; Mn as MnO, 103.6 mg; Cu as $CuSO_4 \cdot 5H_2O$, 15.5 mg; I as $Ca(IO_3) \cdot 6H_2O$, 622 μg; Se as Na_2SeO_3, 311 μg.

stored at $-18^{\circ}C$ for analysis. Two 24 h measurements of gas exchange in two open-air circuit respiration chambers were performed during the second and third day of each balance period. Heat production was calculated from the gas exchange measurements (VO_2 and VCO_2) and the carbon and nitrogen balance measurements according to Brouwer (1965). Measurements were done on two cages including four birds. Further details about the respiration chambers and the employed procedure are given by Jørgensen et al. (1996b).

After completion of the experiment the animals were killed by mechanical stunning and the content of the gastrointestinal (GI) tract was removed and weighed and the weight

of the digesta-free empty body and GI tract of each chick were recorded. The heart and liver were also weighed. Digesta content of the last 10 cm of the small intestine was collected for estimation of ileal digestibility. Feed and water was available until killing to ensure digesta to be analysed at the ileum.

2.3. Analytical methods

All analyses were carried out on freeze-dried material except the diets, which were analysed on an air-dry basis. DM content of feed and droppings was determined by oven drying at 105°C for 20 h. All the following analyses were done in duplicate: protein (N · 6.25) by a modified Kjeldahl method (93/28/EEC) using a Kjell-Foss 16200 autoanalyser (Foss Electric, Hillerød, Denmark). Energy was determined with a LECO Ac 300 automated calorimeter system 789-500 (LECO, St Joseph, Michigan, USA) (ISO 9831:1998). Carbon was measured by means of electrical conductivity as described by Neergaard et al. (1969). Fat (HCl-fat) was extracted with diethyl ether after acid-hydrolysis (Stoldt 1952) and the composition and amount of fatty acid methyl esters were measured using gas-liquid chromatography after saponification and methylation as described by Rotenberg and Andersen (1980) with substitution of hexane with heptane and with C17:0 as the internal standard. Chromic oxide was measured using the method of Schürch et al. (1950). Starch was measured by the enzymatic procedure reported by Bach Knudsen et al. (1993).

2.4. Calculations and statistical analyses

All calculations of gas exchange were carried out on the means of four chickens as kept in the respiration chambers while the other data was calculated on the basis of two chickens kept in the same cage. All statistics were analysed by using the MIXED procedure of SAS (Littell et al. 1996). Mean values are reported as Least square means (LSMeans) values and root mean square error (RMSE) and statistical significance was detected when $p < 0.05$. Dietary effects on animal performance and organ characteristics were analysed using the following normal model:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \varepsilon_{ijk}$$

Digestibility of nutrients and metabolism of energy and protein were analysed using the model:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma(\beta)_{jk} + \varepsilon_{ijk}$$

Y_{ijk} is the observed independent variable, μ is the overall mean of the observations, α_i is the main effect of rapeseed oil (i = 0, 4, 8, 16%), β_j is the effect of series (j = 1, 2), γ $(\beta)_{jk}$ is the effect of period (k = 1, 2, 3) within series and ε_{ijk} is the residual error component.

3. Results

Due to technical reasons all data from period 3 was deleted. Body-weight gain was higher when rapeseed oil was added (Table 2) in accordance with the supplied ME intake (cf. Table 4). No effects ($p > 0.05$) of dietary inclusion of rapeseed oil on liver and heart weight relative to empty body weight (EBW) were found. Digesta weight in the

Table 2. Influence of increasing levels of dietary rapeseed oil on performance, visceral organs and gastrointestinal tract in broiler chicken.

	Dietary rapeseed oil [%]					
	0	4	8	16	RMSE*	Effect[#]
Initial body weight [g]	246	243	246	246	14	NS
Final body weight [g]	1667	1739	1745	1734	110	NS
Daily gain [g/d]	45.9	48.3	48.3	48.0	3.5	L, Q
Gutfill [g/kg BW]	29.4	35.4	44.2	61.0	12.2	L
Organ weight [g/kg EBW[†]]						
Liver	26.8	26.9	26.9	27.6	4.4	NS
Heart	4.7	4.7	5.0	5.0	0.6	NS
Gastrointestinal tract weight [g/kg EBW]						
Crop	3.0	4.4	4.7	6.1	0.7	L
Gizzard	16.7	19.4	19.8	19.8	2.7	NS
Stomach	4.0	4.6	4.2	4.5	0.6	NS
Small intestine	24.0	25.1	25.1	28.0	2.4	L
Caecum[+]	4.5	4.3	4.0	4.2	0.9	NS
Colon	1.4	1.3	1.2	1.2	0.3	NS
Total digestive tract	53.7	59.3	58.9	63.9	5.0	L
Gastrointestinal tract length [cm/kg EBW]						
Small intestine	93.0	88.7	91.2	104.2	8.5	L
Caecum	9.6	9.1	9.4	9.4	0.8	NS
Colon	3.0	2.9	2.7	3.1	0.4	NS

Notes: Body weight of individual chicks including extra chickens, $n = 12$; daily gain mean of cage with two chickens, $n = 6$; slaughter analysis data individual chicks, $n = 8$; *RMSE, root mean square of the residual error and applies to the whole model; [#]NS, not significant; L, linear; Q, quadratic; [†]EBW = empty body weight; [+]Mean of both caeca.

gastrointestinal (GI) tract (gutfill) increased linearly in relation to dietary fat intake (2 g for each percentage rapeseed oil added) indicating a slower rate of passage. Both the empty weight and the length of the small intestine increased with increasing rapeseed oil in the diet ($p < 0.05$); in particular the crop increased considerably in weight relative to EBW ($p < 0.05$).

The ileal digestibility of dry matter and crude protein, measured using chromic oxide as indicator when the chicks were slaughtered, did not differ significantly between the dietary treatments (Table 3). The result of the faecal digestibility is shown as the overall mean of all periods as no significant interactions between periods and diets were detected. The inclusion of rapeseed oil had no influence on digestibility of dry matter and organic matter. The digestibility of fat increased from 51–89% with addition of rapeseed oil, whereas the digestibility of the total carbohydrate (starch + sugar + fibre) dropped from 81–77%. The metabolisability (ME in % of GE) increased with inclusion of rapeseed oil in the diet.

The intention was to supply the chickens with equal daily amounts of essential nutrients as protein, amino acids and minerals. This was also achieved as there was only minor difference in either protein intake or protein retention (Table 4). The apparent fat digestibility increased with level of inclusion since lower proportion of endogenous. There was no significant difference in ME-intake between the treatments, which was in accordance with the experimental design. The supplied ME was used differently among the

Table 3. Effect of increasing levels of dietary rapeseed oil on ileal ($n = 4$) and faecal ($n = 12$) digestibility in broiler chickens.

	Dietary rapeseed oil [%]					
	0	4	8	16	RMSE*	Effect[#]
Ileal digestibility [%]						
DM	69.0	64.5	68.2	70.1	4.7	NS
Protein	76.9	79.2	76.6	80.2	3.9	NS
Faecal digestibility [%]						
DM	73.2	72.4	73.4	73.2	1.2	NS
Organic matter	75.3	74.9	75.7	75.9	1.2	NS
HCl-fat	50.5	76.7	84.7	88.9	2.7	L, Q
Carbohydrate	80.9	80.5	79.0	76.7	1.2	L
Metabolisability (ME/GE) [%]	74.2	74.9	77.0	78.3	1.2	L

Notes: *RMSE, root mean square of the residual error and applies to the whole model; [#]NS, not significant; L, linear; Q, quadratic.

Table 4. Effect of increasing levels of dietary rapeseed oil on protein, fat and energy balance in broiler chickens[†].

	Dietary rapeseed oil [%]					
	0	4	8	16	RMSE*	Effect[#]
Protein balance						
Protein intake [g/d]	21.2	22.3	19.9	20.6	1.3	L
Protein in excreta [g/d]	8.4	8.8	7.4	7.4	0.7	L
Protein in excreta [% intake]	39.4	38.7	36.1	35.3	2.7	L
Retained protein [g/d]	12.8	13.5	12.5	13.2	1.0	NS
Retained protein [% intake]	60.6	61.3	63.9	64.7	2.7	L
Fat balance						
Fat intake [g/d]	2.6	6.5	9.8	14.2	1.9	L
Fat digested [g/d]	1.3	5.1	8.4	12.7	1.9	L
Retained fat [g/d]	8.3	9.4	9.9	10.4	1.3	L
Energy balance						
GE intake [kJ/d]	1741	1774	1725	1702	57	NS
ME intake [kJ/d]	1266	1305	1308	1298	54	NS
Retained energy [kJ/d]	634	695	691	731	63	L
Heat energy [kJ/d]	633	611	617	567	38	L
Respiratory quotient	0.96	0.94	0.88	0.86	0.04	L

Notes: [†]Protein balance: mean of cages, $n = 12$, fat and energy balance: mean of two cages in respiration chamber, $n = 6$; *RMSE, root mean square of the residual error and applies to the whole model; [#]NS, not significant; L, linear.

dietary groups. The general trend was that increasing inclusion of rapeseed oil increased energy retention from 634–731 kJ/d, while the heat energy (HE) concomitantly decreased from 633–567 kJ/d. The respiratory quotient (RQ) decreased linearly with increasing inclusion level of rapeseed oil.

The content of metabolisable energy (MJ/kg DM) in diets increased linearly ($p < 0.005$) with increasing inclusion level of rapeseed oil in diets (Table 5), which is to

be expected with the high energy density of rapeseed oil. The high efficient utilisation of rapeseed oil was illustrated by decreasing heat production expressed as HE (MJ/kg DM) or relative to ME intake (HE/ME) [%] and increasing retention of energy both expressed as MJ/kg DM and relatively to ME (RE/ME) [%]. There was deposited relative more energy as fat (RE-fat in % of RE) and less energy as protein (RE-protein in % of RE) with increasing intake of rapeseed oil. Expressing ME and RE in relation to metabolic live weight ($W^{0.75}$) showed the same trend as described above.

Partial fat digestibility and partial energy utilisation of the basal diet and the added rapeseed oil was found by regression analysis (Table 6). The digestibility of fat in rapeseed oil was found to be 91.1%, in contrast to the much lower value of fat digestibility in the basal diet (60.2%). Similar use of the regression analysis to estimate the utilisation of the gross energy (GE) of the basal diet and the added rapeseed oil showed that 85% of GE in rapeseed oil could be used for metabolism in the body, thus resulting in an apparent metabolisable energy (AME) value of 34.30 MJ/kg (GE of rapeseed oil 40.35 MJ/kg · 0.85). The regression analysis revealed in similar ways that 26.2% of GE

Table 5. Effect of increasing levels of dietary rapeseed oil on energy utilisation in broiler chickens[†].

	Dietary rapeseed oil [%]					
	0	4	8	16	RMSE*	Effect[#]
ME [MJ/kg DM]	13.32	14.14	15.33	16.40	0.37	L
Heat energy [MJ/kg DM]	6.79	6.78	7.23	7.28	0.50	L (0.059)
RE[+] [MJ/kg DM]	6.53	7.36	8.09	9.12	0.54	L
Heat energy/ME [%]	51.1	48.1	47.3	44.3	3.5	L
RE/ME [%]	48.9	51.9	52.7	55.7	3.5	L
RE-fat /RE [%]	49.1	50.9	55.7	55.6	4.1	L
RE-protein/RE [%]	50.9	49.1	44.3	44.4	4.1	L
ME [kJ/kg $W^{0.75}$]	1411	1409	1563	1552	91	L
Heat energy [kJ/kg $W^{0.75}$]	717	676	735	691	48	NS
RE [kJ/kg $W^{0.75}$]	694	733	828	861	82	L

Notes: [†]Energy utilisation: mean of two cages in respiration chamber, $n = 6$; *RMSE, root mean square of the residual error and applies to the whole model; [#]NS, not significant; L, linear; Q, quadratic; [+]RE, retained energy.

Table 6. Partial fat digestibility and energy efficiency of gross energy (GE) [MJ/d] from the basal diet and rapeseed oil estimated as the regression coefficient from the equation $Y = \mu + b_1 \times$ energy-basal $+ b_2 \times$ energy-rapeseed oil with intercept (μ).

	Model with intercept (μ)		
	Intercept (μ)	Basal (b_1)	Rapeseed oil (b_2)
Fat digestibility	−0.13	0.602	0.911
	$p = 0.346$	SE* = 0.041	SE = 0.008
Metabolisable energy/ gross energy	−12.2	0.736	0.850
	$p = 0.487$	SE = 0.010	SE = 0.022
Heat energy/gross energy	45.2	0.334	0.262
	$p = 0.272$	SE = 0.023	SE = 0.052
Retained energy/gross energy	−57.4	0.401	0.588
	$p = 0.198$	SE = 0.025	SE = 0.056

Notes: *SE, standard error of estimate; Intercepts were significantly different from zero at $p < 0.05$.

would be dissipated as heat and 58.8% of GE could be expected to be retained as energy in the body.

4. Discussion

When comparing rapeseed oil with soybean oil, rapeseed oil has about a two-fold higher content of oleic acid (18:1n-9) while linoleic acid (18:2n-6), the precursor of arachidonic acid (20:4n-6), is 50% lower (Jørgensen and Fernández 2000). Linolenic acid (18:3n-3), the precursor for the nutritionally important fatty acids 20:5n-3, 22:5n-3 and 22:6n-3, is also in higher concentrations in rapeseed oil than in soybean oil and especially higher than in sunflower oil (Wiseman et al. 1992; Ortiz et al. 1998) or palm oil (Zumbado et al. 1999). Double low rapeseed like the one used in the present experiment had a content of the unwanted erucic acid (22:1n-9) that was below the detection limit.

All chickens obtained similar daily amounts of ME as determined in energy balance studies (Table 4). The rapeseed oil linearly increased the amount of gutfill by 2 g/kg BW for each percent of added rapeseed oil. This is within the same range as reported for broiler chickens fed increasing levels of dietary fibre (Jørgensen et al. 1996b) and the result demonstrates that gutfill may contribute significantly to live weight depending on diet composition. The explanation is likely a slower rate of passage as fat is shown to slow down the gastrointestinal emptying (Gregory et al. 1989).

The empty weight of the crop, small intestine and subsequently of the total digestive tract was significantly increased with higher dietary fat content and the length of the small intestine increased as well. Dänicke and co-workers (2000) found similarly that increasing addition of fat in form of tallow in a rye based diet increased the empty weight of small intestine which they suggested could be a result of trophic effect on the intestinal mucosa together with an increased viscosity. In another experiment with broiler chickens fed increasing amount of specific structured triacylglycerides at the expense of rapeseed oil Zheng et al. (2006) reported a decreasing weight of the small intestine and colon. A similar hypertrophy of gut tissues has been found in studies on different types of dietary fibres (Savory 1992; Jørgensen et al. 1996a; Simon 1998), and with other animal species such as the rat (Hansen et al. 1992; Zhao et al. 1995) and pig (Jørgensen et al. 1996c). Thus, there is ample evidence that dietary fibre may cause a significant expansion of the gastrointestinal tract. In the present experiment the relative proportion of starch from pea increased with added rapeseed oil according to the experimental design and pea starch is shown to be less digestible than starch from wheat (Weurding et al. 2001; Carré 2004). Therefore, it cannot be excluded that the increased hypertrophy of the gastrointestinal tract has an impact on intestinal microflora, viscosity of the digesta and intestinal transit time (Dänicke et al. 1999a; Knarreborg et al. 2002; Maisonnier et al. 2003).

Digestion of fat in poultry is to a large extent depending on bile salt secretion (Kussaibati et al. 1982; Krogdahl 1985; Knarreborg et al. 2003), and is a limiting factor for the micelle formation especially in young birds fed unsaturated fatty acids (Wiseman and Lessire 1987). The curvilinear pattern of fat digestibility shown in Table 3 demonstrates that endogenous fat originating from bile (Jørgensen et al. 1992a), desquamated cells or exudation from the mucosa had higher impact on the apparent fat digestibility at low dietary fat levels than at higher levels (Jørgensen et al. 1993). Expressing the intake of dietary fat on digested amount of fat in absolute amounts a linear relationship is revealed and the partial digestibility of fat can be found by

regression (Jørgensen and Fernández 2000). The digestibility of rapeseed oil was relatively high (91.1%; Table 6) and similar to refined sunflower oil (Wiseman et al. 1992), but lower than the digestibility of fat in full-fat sunflower (Ortiz et al. 1998) and that in rapeseed meal (Chibowska et al. 2000).

The ileal dry matter and protein digestibility in the present experiment (Table 3) was in the same range as found by Dänicke et al. (1999b) in experiment with broilers feeding either soybean oil or tallow based diet. Increased utilisation of dietary protein (retained protein % of protein intake; Table 4) suggests a positive effect of the supplied rapeseed oil as also shown in a previous experiment with growing pigs (Jørgensen et al. 1996a). Li and Sauer (1994) found in experiments with pigs that the ileal digestibility of most amino acids increased linearly with addition of rapeseed oil. The effect of additional dietary fat on protein digestibility could be caused by delayed gastric emptying (Hunt and Knox 1968), thus supplying the intestine with a more uniform flow of digesta. However, as should be pointed out other factors could also contribute to increased protein utilisation. A higher proportion of the dietary protein was supplied by soybean meal and crystalline amino acids with higher protein digestibility and less pea protein with lower protein digestibility (Perez et al. 1993; Grosjean et al. 1999). The decreased digestibility of total carbohydrate (starch + sugar + fibre) seen when rapeseed oil was added could be explained by a relative higher proportion of carbohydrate from pea at the expense of carbohydrate from wheat. Starch from pea is more resistant to the digestive enzymes than starch from cereals as wheat due to the starch granule structure (Grosjean et al. 1999; Weurding et al. 2001; Carré 2004).

The estimated AME value of 34.30 MJ/kg DM was in the same range as that reported for other vegetable fat sources of similar fatty acid profile (Renner and Hill 1960; Huyghebaert et al. 1988; Wiseman et al. 1992). A lower AME value of rapeseed oil (33.5 MJ/kg) is published by Scheele et al. (1999) and a higher (35.6 MJ/kg) in the European Table of Energy Values for Poultry Feedstuffs (Working Group no. 2, 1989). The AME value found in the present study was somewhat lower than found for growing pigs (38.28 MJ/kg) in a similar study design (Jørgensen et al. 1996a). In a comprehensive study Sibbald et al. (1990) compared AME between pigs and cockerels (84 samples) and found that pig AME value were generally higher than the poultry AME. The best relationship of AME values was found for cereals and mixed diets. Likewise, Wiseman et al. (1998) found a close relation between AME value of fats and oils between pigs and poultry except in very young birds (1.5 weeks of age).

The intention was to feed all groups of chickens equal daily amounts of ME which was also achieved, except for a slightly lower intake in chickens fed the control diet (Table 4). The daily gain (Table 2) followed thus closely the ME intake. With more rapeseed oil in the diet the supplied ME substrate changed the energy utilisation towards more energy deposited as fat and less deposited as protein and carbohydrate. This is also reflected by the improved efficiency of energy for retention. Heat energy relative to ME decreased and consequently more energy is available for retention. This is in agreement with the generally accepted view that ME from fat has a much higher efficiency than ME derived from protein, starch or fibre (Just 1982; Jørgensen et al. 1996a). However, the higher GI tract hypertrophy in chickens fed high level of rapeseed oil suggests that part of the energy is retained in visceral organs and not solely in muscles.

In conclusion, rapeseed oil has been found to have a positive effect on feed utilisation as well as digestibility of nutrients and energy and utilisation of protein. Thus, could exert positive impact on reducing the nitrogen excretion and be of benefit for the environment.

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References

Bach Knudsen KE, Jensen BB, Hansen I. 1993. Digestion of polysaccharides and other major components in the small and large intestine of pigs fed on diets consisting of oat fractions rich in β-D-glucan. Brit J Nutr. 70:537–556.

Brouwer E. 1965. Report of sub-committee on constants and factors. In: Blaxter KL, editor. Energy metabolism. London: Academic Press. p. 441–443.

Carré B. 2004. Causes for variation in digestibility of starch among feedstuffs. World Poult Sci J. 60:76–89.

Chibowska M, Smulikowska S, Pastuszewska B. 2000. Metabolisable energy value of rapeseed meal and its fractions for chickens as affected by oil and fibre content. J Anim Feed Sci. 9:371–378.

Dänicke S, Franke E, Strobel E, Jeroch H, Simon O. 1999a. Effects of dietary fat type and xylanase supplementation in rye containing diets on energy metabolism in male broilers. J Anim Physiol Anim Nutr. 81:90–102.

Dänicke S, Jeroch H, Bottcher W, Simon O. 2000. Interactions between dietary fat type and enzyme supplementation in broiler diets with high pentosan contents: Effects on precaecal and total tract digestibility of fatty acids, metabolizability of gross energy, digesta viscosity and weights of small intestine. Anim Feed Sci Technol. 84:279–294.

Dänicke S, Simon O, Jeroch H, Keller K, Glaser K, Kluge H, Bedford MR. 1999b. Effects of dietary fat type, pentosan level and xylanase supplementation on digestibility of nutrients and metabolizability of energy in male broilers. Arch Anim Nutr. 52:245–261.

Engberg RM, Lauridsen C, Jensen SK, Jakobsen K. 1996. Inclusion of oxidized vegetable oil in broiler diets. Its influence on nutrient balance and on the antioxidative status of broilers. Poult Sci. 75:1003–1011.

Gregory PC, McFadyen M, Rayner DV. 1989. Control of gastric emptying in the pig: Influence of duodenal infusions of glucose and emulsified fat. Q J Exp Physiol. 74:109–119.

Grosjean F, Barrier-Guillot B, Bastianelli D, Rudeaux F, Bourdillon A, Peyronnet C. 1999. Feeding value of three categories of pea (*Pisum sativum*, L.) for poultry. Anim Sci. 69:591–599.

Hansen I, Bach Knudsen KE, Eggum BO. 1992. Gastrointestinal implications in the rat of wheat bran, oat bran and pea fibre. Brit J Nutr. 68:421–462.

Hulan HW, Proudfoot FG, Nash DM. 1984. The effects of different dietary fat sources on general performance and carcass fatty acid composition of broiler chickens. Poult Sci. 63:324–332.

Hunt JN, Knox MT. 1968. A relation between the chain lenght of fatty acids and the slowing of gastric emptying. J Physiol. 194:327–336.

Huyghebaert G, de Munter G, de Groote G. 1988. The metabolizable energy (AMEn) of fats for broilers in relation to their chemical composition. Anim Feed Sci Technol. 20:45–58.

Jakobsen K. 1999. Dietary modifications of animal fats: Status and future perspectives. Fett/Lipid. 101:475–483.

Jørgensen H, Fernández JA. 2000. Chemical composition and energy value of different fat sources for growing pigs. Acta Agric Scand Sect A-Anim Sci. 50:129–136.

Jørgensen H, Jakobsen K, Eggum BO. 1992a. Excretion of biliary fat and fatty acids in growing pigs. J Anim Feed Sci. 1:139–149.

Jørgensen H, Jakobsen K, Eggum BO. 1992b. The influence of different protein, fat and mineral levels on the digestibility of fat and fatty acids measured at the terminal ileum and in faeces of growing pigs. Acta Agric Scand Sect A-Anim Sci. 42:177–184.

Jørgensen H, Jakobsen K, Eggum BO. 1993. Determination of endogenous fat and fatty acids at the terminal ileum and on faeces in growing pigs. Acta Agric Scand Sect A-Anim Sci. 43:101–106.

Jørgensen H, Jensen SK, Eggum BO. 1996a. The influence of rapeseed oil on digestibility, energy metabolism and tissue fatty acid composition in pigs. Acta Agric Scand Sect A-Anim Sci. 46:65–75.

Jørgensen H, Zhao XQ, Bach Knudsen KE, Eggum BO. 1996b. The influence of dietary fibre source and level on the development of the gastrointestinal tract, digestibility and energy metabolism in broiler chickens. Brit J Nutr. 75:379–395.

Jørgensen H, Zhao XQ, Eggum BO. 1996c. The influence of dietary fibre and environmental temperature on the development of the gastrointestinal tract, digestibility, degree of fermentation in the hind-gut and energy metabolism in pigs. Brit J Nutr. 75:365–378.

Just A. 1982. The net energy value of crude fat for growth in pigs. Livest Prod Sci. 9:501–509.

Knarreborg A, Jensen SK, Engberg RM. 2003. Pancreatic lipase activity as influenced by unconjugated bile acids and pH, measured *in vitro* and *in vivo*. J. Nutr Biochem. 14:259–265.

Knarreborg A, Simon MA, Engberg RM, Jensen BB, Tannock GW. 2002. Effects of dietary fat source and subtherapeutic levels of antibiotic on the bacterial community in the ileum of broiler chickens at various ages. Appl Envinron Microbiol. 68:5918–5924.

Krogdahl Å. 1985. Digestion and absorption of lipids in poultry. J Nutr. 115:675–685.

Kussaibati R, Guillaume J, Leclercq B. 1982. The effects of age, dietary fat and bile salts, and feeding rate on apparent and true metabolisable energy values in chickens. Brit Poult Sci. 23:393–403.

Li S, Sauer WC. 1994. The effect of dietary fat content on amino acid digestibility in young pigs. J Anim Sci. 72:1737–1743.

Littell RC, Milliken GA, Stroup WW, Wolfinger RD. 1996. SAS® System for Mixed Models. Cary (NC): SAS Institute Inc. p. 633.

Maisonnier S, Gomez J, Brée A, Berri C, Baéza E, Carré B. 2003. Effects of microflora status, dietary bile salts and guar gum on lipid digestibility, intestinal bile salts, and histomorphology in broiler chickens. Poult Sci. 82:805–814.

Mlodkowski M, Swiatkiewicz S, Koreleski J, Kubicz M. 2003. The effect of supplemental vitamin E and dietary rape seed oil level on broiler performance, meat and fat quality. J Anim Feed Sci. 12:121–132.

Neergaard L, Bønsdorff Petersen C, Thorbek G. 1969. Carbon determination in biological materials related to respiration trials. Z Tierphysiol Tierernährg u Futtermittelkde. 25:302–308.

Nir I, Twina Y, Grossman E, Nitsan Z. 1994. Quantitative effects of pelleting on performance, gastrointestinal-tract and behavior of meat-type chickens. Brit Poult Sci. 35:589–602.

Olomu JM, Baracos VE. 1991. Influence of dietary flaxseed oil on the performance, muscle protein deposition, and fatty acid composition of broiler chicks. Poult Sci. 70:1403–1411.

Ortiz LT, Rebole A, Rodriguez ML, Trevino J, Alzueta C, Isabel B. 1998. Effect of chicken age on the nutritive value of diets with graded additions of full-fat sunflower seed. Brit Poult Sci. 39:530–535.

Perez L, Fernandez-Figares I, Nieto R, Aguilera JF, Prieto C. 1993. Amino acid ileal digestibility of some grain legume seeds in growing chickens. Anim Prod. 56:261–267.

Renner R, Hill FW. 1960. The utilization of corn oil, lard and tallow by chickens of various ages. Poult Sci. 39:849–854.

Rotenberg S, Andersen JO. 1980. The effect of dietary citrus pectin on fatty acid balance and the fatty acid content of the liver and small intestine in rats. Acta Agric Scand. 30:8–12.

Savory CJ. 1992. Gastrointestinal morphology and absorption of monosaccharides in fowls conditioned to different types and levels of dietary fibre. Brit J Nutr. 67:77–89.

Scaife JR, Moyo J, Galbraith H, Michie W, Campbell V. 1994. Effect of different dietary supplemental fats and oils on the tissue fatty-acid composition and growth of female broilers. Br Poult Sci. 35:107–118.

Scheele CW, Kwakernaak C, van der Klis JD, Bakker GCM. 1999. Effects of different factors including enzymes on the nutritional value of fats for poultry. In: Wiseman J, Garnsworthy PC, editors. Recent developments in poultry nutrition 2. Nottingham: Nottingham University Press. p. 269–284.

Schürch AF, Lloyd LE, Crampton EW. 1950. The use of chromic oxide as an index for determining the digestibility of a diet. J Nutr. 41:629–636.

Sibbald IR, Hall DD, Wolynetz MS, Fernández JA, Jørgensen H. 1990. Relationships between bioavailable energy estimates made with pigs and cockerels. Anim Feed Sci Technol. 30:131–142.

Simon O. 1998. The mode of action of NSP hydrolysing enzymes in the gastrointestinal tract. J Anim Feed Sci. 7:115–123.

Stoldt W. 1952. Vorslag zur Vereinheitlichung der Fettbestimmung in Lebensmitteln. Fette und Seifen. 54:206–207.

Straarup EM, Danielsen V, Hoy CE, Jakobsen K. 2006. Dietary structured lipids for post-weaning piglets: Fat digestibility, nitrogen retention and fatty acid profiles of tissues. J Anim Physiol Anim Nutr. 90:124–135.

Weurding RE, Veldman A, Veen WAG, van der Aar PJ, Verstegen MWA. 2001. Starch digestion rate in the small intestine of broiler chickens differs among feedstuffs. J Nutr. 131:2329–2335.
Wiseman J, Edmunds BK, Shepperson N. 1992. The apparent metabolisable energy of sunflower oil and sunflower acid oil for broiler chickens. Anim Feed Sci Technol. 36:41–51.
Wiseman J, Lessire M. 1987. Interactions between fats of differing chemical content: apparent metabolisable energy values and apparent fat availability. Brit Poult Sci. 28:663–676.
Wiseman J, Powles J, Salvador F. 1998. Comparison between pigs and poultry in the prediction of the dietary energy value of fats. Anim Feed Sci Technol. 71:1–9.
Wiseman J, Salvador F. 1989. Influence of age, chemical composition and rate of inclusion on the apparent metabolisable energy of fats fed to broiler chicks. Brit Poult Sci. 30:653–662.
Working Group No 2. 1989. European Table of Energy Values for Poultry Feedstuffs. 3rd ed. Wageningen: Spelterholt Centre for Poultry Research and Extension. p. 24.
Zhao XQ, Jørgensen H, Eggum BO. 1995. The influence of dietary fibre on body composition, visceral organ weight, digestibility and energy balance in rats housed in different thermal environments. Brit J Nutr. 73:687–699.
Zheng C-T, Jørgensen H, Høy C-E, Jakobsen K. 2006. Effects of increasing dietary concentrations of specific structured triacylglycerides on performance and nitrogen and energy metabolism in broiler chickens. Brit Poult Sci. 47:180–189.
Zollitsch W, Knaus W, Aichinger F, Lettner F. 1997. Effects of different dietary fat sources on performance and carcass characteristics of broilers. Anim Feed Sci Technol. 66:63–73.
Zumbado ME, Scheele CW, Kwakernaak C. 1999. Chemical composition, digestibility, and metabolizable energy content of different fat and oil by-products. J Appl Poult Res. 8:263–271.