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The influence of an isocaloric substitution of soya bean oil for carbohydrates and of the nutrient density of the feed on growth and efficiency of energy utilization in broiler chickens

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Summary

In an experiment with five-week-old broiler chickens lasting 14 days, we studied the influence on the efficiency of energy utilization of an isocaloric substitution of soya bean oil for carbohydrates in rations with 4 different calorie:protein ratios. The consumption of protein, minerals and vitamines was the same for all 8 experimental treatments. In a number of experimental animals the energy balance was determined by means of the comparative slaughter method. A decrease in the dietary energy from carbohydrates resulted in lower energy retention, mainly as a result of lower fat deposition. Isocaloric substitution of soya bean oil for carbohydrates had no effect on body composition of the animals, but it increased growth rate and energy retention and so improved efficiency of utilization of metabolizable energy.

In a second experiment, also involving 5-week-old broiler chickens, we studied the effect of an isocaloric substitution of soya bean oil for carbohydrates, using two different calorie: protein ratios, with or without the addition of sand or cellulose as a diluent in the rations with a high fat content. The isocaloric substitution of fat for carbohydrates in this experiment also resulted in improved efficiency of energy utilization. The addition of a diluent to the ration high in fat had no detrimental effect on efficiency of energy utilization. Reducing calorie: protein ratio increased growth rate, but also led to less efficient energy utilization, as a result of lower carcass fat deposition.

Introduction

Nitrogen-corrected metabolizable energy is generally used for the energetic evaluation of poultry feeds. In this system the energetic value of fats sometimes seems to be underestimated. American research workers therefore sometimes mention an extra-energetic effect of fats in poultry feeds. Two possible explanations can be given for this extra-energetic effect: (1) a positive influence of some fats on the digestibility of the ration (increase of metabolizable energy (ME) content), or (2) an increase of the efficiency of utilization of metabolizable energy (increase of net energy content).

Metabolizable energy content. In determining ME values of fats it is common practice to use a basal diet and a number of test diets, containing varying proportions of the basal diet and fat. The ME value of the fat is obtained by extrapolation to 100 % fat. By this method, sometimes ME values are found for fats that are in excess of gross energy values. This can be explained by assuming a synergism of the fatty acids in the basal diet with those of the added fat, resulting in increased digestibility of the mixture (Leeson & Summer, 1976).

Another explanation is given by Mateos & Sell (1980 a, b, c) who assume a better digestibility of all nutrients in the basal diet, due to a slowing down by fat of the rate of passage of the feed through the gastro-intestinal tract.

Utilization of metabolizable energy. The utilization of metabolizable energy for production may be higher in rations rich in fat, as more fatty acids can be deposited directly into the adipose tissue. As regards energy utilization this process is more efficient than the lipogenesis from carbohydrates.

Moreover, due to a higher nutrient density of rations rich in fat, the intake of such more concentrated feeds requires less energy for physical activity than the intake of bulky feeds of low nutrient density, resulting in more energy available for production (Jensen, 1974). A parallel can be drawn between this phenomenon and the effect of pelleting; the intake of pellets also requires less energy than that of mash (Wenk & van Es, 1979).

In many experiments in which dietary fat was substituted for carbohydrates, lack of measurement of the metabolizable energy of the experimental feeds did not allow to conclude whether the influence of the fat was due to an effect on digestibility (ME) or on the utilization of the ME. In most cases energetic efficiency could not be determined exactly because only weight gain and feed consumption were recorded but not energy gain. In some energy balance studies just fat was substituted for carbohydrates with concomitant concentration of the feed, while in others a mixture of fat and indigestible filler was used, the addition of fat being linked to the presence of filler.

The experiments being presented were designed to determine the effect on energy utilization of an isocaloric substitution of fat for carbohydrate without the use of diluents and with energy consumption remaining constant (Experiment 1) and to determine the effect of indigestible fillers with different density (Experiment 2).

Materials and methods

Experiment 1

Thousand day-old chicks (♀♀) were kept in battery brooders and fed a commercial broiler feed until they were five weeks of age. At that time 960 chicks were randomly distributed into 32 groups of 30 birds each in such a way that the average weight per group was approximately the same. From 5 to 7 weeks of age, each of the 8 experimental diets of Table 1 was given to four replicates of 30 animals each. The animals receiving diet 1 were fed approximately ad libitum; the other diets were fed as indicated in Table 1. So it was possible to ensure that all 8 treatments received the same quantity of basal feed (protein, minerals and vitamins). The amount of metabolizable energy per 40 g of basal diet was reduced in four stages of 59.4 kJ each (1 kJ $\approx$ 0.239 kcal). This was done by reducing the amount of carbohydrates (maize starch, sucrose mixture) by 4 g per 40 g of basal diet. In addition, in half of the rations (Nos 5, 6, 7 and 8) 6 g of soya bean oil was used to replace an isocaloric amount of carbohydrates (15.4 g) per 40 g basal diet.

We assumed that the gradual reduction in the amount of dietary carbohydrates would result in a decline in energy retention, caused primarily by a decreased lipogenesis. In addition, if lipogenesis from dietary lipids requires less energy than that from dietary carbohydrates, energy retention should be higher for all fat-enriched rations than for those with a low fat content. In this way it would be possible to compare the influence of both fat and carbohydrates on energy rentention.

The metabolizable energy (ME) of all the rations was determined by bomb calorimetry of feeds and droppings with chromic oxide as an indigestible marker. Chromic oxide was determined by the method of Petry & Rapp (1970). In all calculations the classical ME was used, no correction being made for nitrogen retention. The animals were weighed at the beginning of the experiment at 5 weeks of age. At that time a sample of 20 birds nearest the mean weight was sacrificed to provide data on initial carcass composition. At the termination of the experiment, at 7 weeks of age, all birds were weighed and a sample of 5 birds from each replicate was sacrificed, homogenized in a meat grinder and freeze-dried. In the freeze-dried, homogenized carcasses crude protein (Kjeldahl) and crude fat (diethyl ether extraction) were determined. In previous experiments we had determined that the caloric value of 1 g of crude protein and 1 g of crude fat could be set at 23.8 kJ and 38.2 kJ respectively, so this values were used in calculating energy gain.

Experiment 2

This experiment was designed to determine the effect of an isocaloric replacement of carbohydrates by soya bean oil in rations without filler and in rations with sand or cellulose as a filler, with two different calorie:protein ratios.

The composition of the 8 experimental diets is to be found in Table 2. All 8 treatments (four replicates of 30 birds each) received the same quantity of metabolizable energy. The animals in treatment 5 were fed approximately ad libitum; the feeding levels of the other treatments are given in Table 2. The animals, some 1000 broiler chickens (♀♀) aged 5 weeks, were housed as in Experiment 1. ME determination, carcass analyses and weight gain were recorded as in Experiment 1.

Table 1. Composition of the experimental rations per 40 g of basic mixture (Experiment 1).

	Low fat content				High fat content			
Ration No →	1	2	3	4	5	6	7	8
basic mixture* (g)	40	40	40	40	40	40	40	40
starch + sucrose (g)	60	56	52	48	44.6	40.6	36.6	32.6
soya bean oil (g)	–	–	–	–	6	6	6	6
sum total; feed level (%)	100	96	92	88	90.6	86.6	82.6	78.6
metabolizable energy (determined) (kJ)	1392	1333	1274	1214	1374	1315	1255	1196
crude protein (calculated) (g)	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
total fat (calculated) (g)	3.2	3.2	3.2	3.2	9.2	9.2	9.2	9.2

* Basic mixture: soya bean oil meal 25 g; fish meal 4 g; soya bean oil 2 g; maize 3.4 g; calcium hydrogen phosphate 1.2 g; vitamin-mineral mixture 2 g; dl-methionin preparation 2.4 g.

Table 2. Composition of the experimental rations (Experiment 2).

	Low protein				High protein			
	low fat	high fat			low fat	high fat		
		undiluted	+ sand	+ cellulose		undiluted	+ sand	+ cellulose
Ration No →	1	2	3	4	5	6	7	8
maize (g)	44.9	44.9	44.9	44.9	40.5	40.5	40.5	40.5
starch + sucrose (g)	23.2	7.8	7.8	7.8	20	4.6	4.6	4.6
soya bean oil meal (g)	22.75	22.75	22.75	22.75	34	34	34	34
soya bean oil (g)	2	8	8	8	2	8	8	8
vitamins + minerals (g)	2	2	2	2	2	2	2	2
calcium hydrogen phosphate (g)	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5
dl-methionin (g)	0.09	0.09	0.09	0.09	0.2	0.2	0.2	0.2
sand (g)	–	–	9.4	–	–	–	9.4	–
cellulose (g)	–	–	–	9.4	–	–	–	9.4
sum total (g); feed level (%)	96.54	87.14	96.54	96.54	100	90.6	100	100
metabolizable energy (determined) (kJ)	1244	1241	1226	1246	1247	1256	1253	1226
crude protein (calculated) (g)	15	15	15	15	20	20	20	20
crude fat (calculated) (g)	4.1	10.1	10.1	10.1	4.1	10.1	10.1	10.1

Results

Experiment 1

The ME values of the experimental feeds agreed reasonably well with the objectives of the experiment (Table 1). The fat-enriched feeds showed a slightly lower ME content than those low in fat.

As is shown in Table 3, the isocaloric substitution of fat for carbohydrates resulted in more rapid growth, without affecting the protein and fat content of the animals at 7 weeks. To the degree that less energy (carbohydrates) was given, the fat content of the animals decreased; the fat content of the ration had no significant effect on this decrease. Although the intake of ME per kg of metabolic weight was slightly lower for the animals receiving rations rich in fat compared with those given a low-fat ration, the energy retention per kg of metabolic weight was highest for the animals on a ration high in fat. Thus the efficiency of ME utilization for the rations high in fat was better than for the low-fat feeds. This is clearly shown in Fig. 1, which shows the relation between energy intake and energy gain. The interaction fat content of the ration × dietary energy was not significant, that is, the slopes of the regression lines in Fig. 1 do not differ significantly. Fig. 1 shows that with energy production equal at, say, 360 kJ, approximately 50 kJ more of the low-fat ration must be consumed than of the feed with a high fat content. On the ration high in fat an animal consumed approximately 5.3 g more fat per day and per kg metabolic weight. This amount of fat (soya bean oil) represents approximately 200 kJ ME. The effect of this amount of ME from soyabean oil was equal to the effect of 200 + 50 kJ = 250 kJ ME from carbohydrates; this means an increase in value of the soya bean oil of approximately 25 %.

Furthermore it will be clear from Table 3 that although all experimental groups consumed the same amount of protein per kg of metabolic weight, as intended, the groups on a high-fat feed still produced more protein than the animals on a low-fat diet. In addition, a decrease in the dietary energy not only resulted in decreased fat formation, but also in decreased protein formation.

Experiment 2

The ME values determined agreed quite well with the intended results (Table 2). The ME content of diets 3 and 8 was somewhat low. No explanation could be found for this. As expected, animals on diets with a high protein content put on weight faster, the fat content of their carcasses being lower than for animals fed on diets with a low protein content (Table 4).

In this experiment isocaloric substitution of fat for carbohydrates also increased rate of growth, and body composition at 7 weeks of age was not significantly affected. The addition of cellulose or sand to the rations high in fat obviously had no effect on growth.

The daily energy retention per animal and per kg metabolic weight was higher for the animals on a low-protein ration than for those receiving a feed high in protein, in spite of the poorer growth rate. This was caused by a larger

Table 3. Results of Experiment 1. The effects of isocaloric substitution of fat for carbohydrate and of the gradual reduction of the dietary energy in the form of carbohydrates.

Ration No →	Low fat 1+2+3+4	High fat 5+6+7+8	Significance	Reduction of dietary energy 1+5	2+6	3+7	4+8	Linear effect
growth per 14 days (g)	513	538	**	562	540	514	487	**
protein content of the animals 7 weeks (%)	19.2	19.2		19.0	19.2	19.1	19.4	*
fat content of the animals 7 weeks (%)	15.0	15.2		15.7	15.4	14.9	14.4	**
energy retention per $kg^{3/4}$ per animal per day (kJ)	354	368	**	398	379	346	320	**
energy consumption per $kg^{3/4}$ per animal per day (kJ)	1155	1134	**	1213	1172	1105	1075	**
fat formed per $kg^{3/4}$ per animal per day (g)	5.58	5.78	**	6.54	6.04	5.41	4.72	**
protein formed per $kg^{3/4}$ per animal per day (g)	5.88	6.15	**	6.20	6.20	5.81	5.85	*
protein consumed per $kg^{3/4}$ per animal per day (g)	13.4	13.3		13.3	13.4	13.3	13.5	

* Significant ($P \leqslant 0.05$) interaction fat content ration × dietary energy.
** Significant ($P \leqslant 0.01$) for all characteristics, not significant.

Table 4. Results of Experiment 2. The effects of a low protein content compared to a high protein content and of an isocaloric substitution of fat for carbohydrates, with and without the addition of cellulose or sand.

	Low protein	High protein	Low fat	High fat		
				no addition	+ sand	+ cellulose
Ration No →	1+2+3+4	5+6+7+8	1+5	2+6	3+7	4+8
growth per 14 days (g)	473	520**	497 a	516 bc	515 bc	510 ac
protein content carcass 7 weeks (%)	19.1	19.3	19.2	18.9	19.0	19.1
fat content carcass 7 weeks (%)	16.1	15.0*	15.5	15.6	15.7	15.8
metabolized energy consumption per $kg^{3/4}$ per animal per day (kJ)	1025	1021	1025 ab	1029 a	1013 b	1017 b
energy retention per $kg^{3/4}$ per animal per day (kJ)	314	307*	305 a	317 b	312 ab	310 ab
K_f +	0.653	0.644	0.633 a	0.653 b	0.666 b	0.655 b

+K_f = energy retention/(ME consumption minus maintenance energy). Maintenance energy = 544 kJ per animal per day per $kg^{3/4}$. Interaction between protein level and fat content NS for all characteristics.
* $P \leqslant 0.05$; ** $P \leqslant 0.01$.
Figures on the same horizontal line with the same letter: difference not significant.

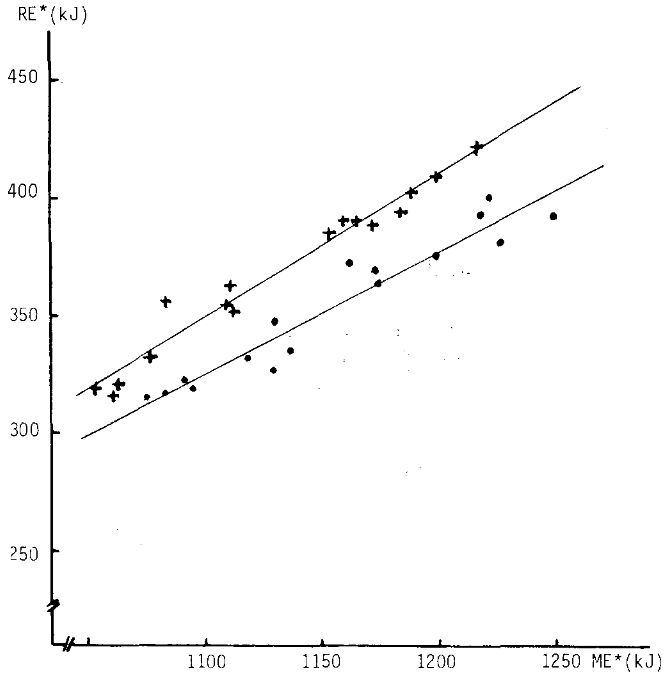

Fig. 1. Energy retention (RE*) as a function of metabolizable energy intake (ME*) in kJ $kg^{-0.75}$.
+ ration rich in fat; ● ration low in fat.

deposition of body fat. Isocaloric substitution of fat for carbohydrates resulted in higher energy retention. In the case of the rations containing sand or cellulose this increase in energy retention was not statistically significant; however the consumption of ME in this rations, notably rations 3 and 8, was also somewhat lower.

Total ME consumed (ME_c) is used for maintenance (ME_m) and production (ME_p), so:

$$ME_c = ME_m + ME_p$$

or per kg metabolic weight $W^{3/4}$:

$$ME_c^* = ME_m^* + ME_p^* \quad (1)$$

If maintenance requirement is assumed to be constant per kg metabolic weight and may be set at 544 kJ, Eq. 1 can be written:

$$ME_p^* = ME_c^* - 544 \quad (2)$$

Energy retention (RE) can be found from carcass composition and is assumed to be proportional to total energy for production (ME_p) or:

$$RE^* = K_f ME_p^* \quad (3)$$

Eq. 2 and 3 yield the relation:

$$K_f = RE^*/(ME_c^* - 544)$$

where K_f is a proportionality factor and is a measure of the efficiency of utilization of ME for production.

For all rations with a high fat content these K_f values are higher than for those low in fat. There was no negative effect of sand or cellulose on energy efficiency (Table 4).

It can be deduced from Table 2 that animals on rations with a low fat content consumed 4.1 g crude fat per 1246 kJ ME taken in. If we assume a digestibility of the dietary fat of 85 % and a calorific value of 39.7 kJ for 1 g digestible fat, then $0.85 \times 4.1 \times 39.7 = 138$ kJ of fat were consumed. So about 11 % of total ME was supplied by fat. For the diets with a high fat content this percentage is approximately 27 %. According to Table 4 the animals fed rations high in fat consumed on average per kg metabolic weight 1020 kJ per animal per day, of which $1020 \times 0.27 = 275$ kJ was in the form of fat, while energy retention was 313 kJ. Apart from maintenance requirement (544 kJ), animals on the low-fat rations would have needed $313/0.633 = 494$ kJ for the production of this 313 kJ, resulting in a total amount of $494 + 544 = 1038$ kJ ME. This is 18 kJ more than the energy consumed by the animals on the high-fat diets. The animals on the low-fat rations would have consumed $1038 \times 0.11 = 114$ kJ in the form of fat, so the 'extracaloric effect' of the replacement of 161 kJ carbohydrates by an isocaloric amount of soya bean oil was $1038 - 1020$ kJ $= 18$ kJ or approximately 11 %.

Discussion

Both experiments showed, that efficiency of ME utilization on rations rich in fat was better than on low-fat feeds. This may be due to the fact that absorbed fatty acids can be deposited directly into the adipose tissue or/and to the higher density of the feeds rich in fat, resulting in a reduction of energy needed for physical activity during feed consumption (Jensen, 1974).

If the extra energetic effect of fat is caused by improved efficiency of ME utilization for production, the magnitude of this effect will largely depend on the fat deposition capacity of the animal and/or on possible alterations of feed density, linked up with the replacement of carbohydrates by fat. In this study isocaloric replacement of carbohydrates by fat had little influence on carcass composition, while a decreasing calorie:protein ratio resulted in a decreased carcass fat content. In this respect the results of our experiments are in agreement with findings of, among others, Rand et al. (1957), Flachowsky & Jeroch (1973), Kirchgessner et al. (1978) and Bartov (1979). Ten Have & Scheele (1981), on the other hand, found that an isocaloric substitution of dietary fat for carbohydrates resulted in a definite increase in fat deposition. If one accepts an extra-energetic effect of dietary fat, replacement of carbohydrates by fat on an ME basis will inadvertently lead to an increased calorie:protein ratio, which is known to favour increased carcass fat deposition.

On the other hand, rate of lipogenesis from carbohydrates is suppressed by dietary lipids (Leclerque, 1972; Madapally et al., 1971; Pearce, 1972; Sallmann & Schole, 1977). The reason for this decreased rate of lipogenesis from carbohydrates is not the fat itself, but rather the relative lack of carbohydrates (Hillard et al., 1980). Thus it seems to be not so much a question of a preferential use of dietary lipids for deposition as carcass fat as a preference on the part of carbohydrates to be used as an energy source in the various tissues.

During Experiment 1 an average of approximately 100 g of body fat was produced per animal (Table 5). During this period 49 g of fat were consumed with the low-fat ration and 141 g with the feed high in fat. If we estimate the digestibility of the fat to be 85 %, this means that 42 and 120 g of fat, respectively, were available to the animal. Thus we know that on the low-fat rations at least 57 % of the body fat is formed from carbohydrates. On the rations with a high fat content, all of the deposited fat could have originated from dietary fat. In Experiment 2 less fat on average was deposited: approximately 82 g. With the low-fat ration, 62 g (approximately 53 g digestible fat) were consumed, as against 152 g (approximately 129 g digestible fat) with the feed rich in fat. This probably explains why the effect of fat in Experiment 2 has less pronounced than in Experiment 1, since fat which is not used for fat deposition was an effective energy value of about 90 % of that of carbohydrates (Scheele et al., 1976).

A negative influence of decreased nutrient density could not be shown in Experiment 2. Other research workers have noted a significantly negative influence of dilution with cellulose (Dale & Fuller, 1979; Dvorak & Bray, 1978; Begin, 1961. Bondsdorf Petersen (1973) fed broiles an equal amount of basal ration, mixed with increasing amount of cellelose; neither digestibility of the basic ration nor growth were affected, but the fat content of the animals decreased as the percentage of cellulose increased, which points to a negative influence on effi-

Table 5. Consumption of digestible fat via the feed and amount of fat produced by the animals in Experiments 1 and 2 where digestibility of the fat is estimated at 85 %.

	Feeds with low fat content		Feeds with high fat content	
	grams of digestible fat consumed	grams of digestible fat produced	grams of digestible fat consumed	grams of digestible fat produced
Experiment 1	42	97	120	101
Experiment 2	52	79	129	84

ciency of energy utilization. Akiba (1979) found no negative effect of cellulose in the case of forced feeding, but only when the animals were fed normally. This would indicate that with energy consumption at the same level, the negative effect of bulky feeds must be ascribed to increased activity necessary for the consumption of these feeds. Wenk & Halter (1979) and Wenk & van Es (1979) observed increased activity due to bulky feeds, in particular in young broilers. It is possible that the effect of cellulose was almost completely lacking in our experiment because of the age of the animals.

Experiment 2 also clearly showed that increased growth rate does not always coincide with improved efficiency of energy utilization. Although the high-protein rations resulted in an increased growth rate in comparison with those low in protein, the energy retention was highest on the low-protein feeds, as a result of the increased fat deposition.

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