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Herbert Kwabla Dei, Paul Rose, Sandy Mckenzie. Apparent metabolisable energy and digestibility of shea (*Vitellaria paradoxa*) fat, cocoa (*Theobroma cacao*) fat and soya bean oil in broiler chicks. *British Poultry Science*, 2006, 47 (05), pp.607-612. 10.1080/00071660600939701 . hal-00545299

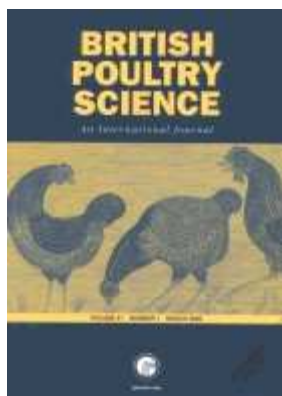
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Journal:	<i>British Poultry Science</i>
Manuscript ID:	CBPS-2005-080.R1
Manuscript Type:	Original Manuscript
Date Submitted by the Author:	08-May-2006
Complete List of Authors:	Dei, Herbert; Harper Adams University College, Animal Science Research Centre Rose, Paul; Harper Adams University College, National Institute of Poultry Husbandry Mckenzie, Sandy; Harper Adams University College
Keywords:	Fats and fatty acids, Broilers, Metabolisable energy, Nutrition



**CBPS\_2005\_080**

edited M G MacLeod, August 2006

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12 5 **Apparent metabolisable energy and digestibility of shea (*Vitellaria paradoxa*) fat, cocoa**  
13 **(*Theobroma cacao*) fat and soya bean oil in broiler chicks**  
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**RUNNING TITLE: SHEA, COCOA AND SOYA FATS**

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Accepted for publication 14<sup>th</sup> June 2006

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3 **Abstract** 1. The objective of this experiment was to determine and compare the apparent  
4 lipid digestibility coefficient and apparent metabolisable energy (AME) value of shea nut  
5 (*Vitellaria paradoxa*, Gaertn.) fat in broiler chickens with that of soya bean oil and cocoa fat.  
6  
7  
8 2. One hundred and sixty 13-d-old male broiler chicks were used in a randomised complete  
9 block design. The fats were added at 30, 60 and 90 g kg<sup>-1</sup> to a basal diet. A tenth dietary  
10 treatment was the basal feed with no added fats or oils. The birds were fed on the diets for 8  
11 d and all droppings were collected for the final 4 d.  
12  
13 3. The mean coefficient of apparent lipid digestibility for shea fat (0.58) was similar to that  
14 of cocoa fat (0.54) but lower than that of soya bean oil (0.95). There was evidence of a lipid  
15 x concentration interaction with the 90 g kg<sup>-1</sup> shea fat diet having low lipid digestibility  
16 (0.43).  
17  
18 4. There was an interaction between the effects of dietary lipid concentration and test lipid  
19 on AME but, at dietary levels of 60 g kg<sup>-1</sup> and below, the AME of shea fat (22.0 MJ kg<sup>-1</sup>  
20 DM) and cocoa fat (26.4 MJ kg<sup>-1</sup> DM) was significantly lower than that of soya bean oil  
21 (39.8 MJ kg<sup>-1</sup> DM).

## INTRODUCTION

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Shea fat is obtained from the nuts of the shea tree (*Vitellaria paradoxa*, Gaertn.) It is the  
most common tree found in the Sahelian parklands over a large area of Africa (Leakey,  
1999). It is used extensively as cooking oil in some communities in West Africa (Hall *et al.*,  
1996). The amount of nuts collected and processed has been increasing over the past decade  
as a consequence of increasing exports of the fat. There are potential reductions in costs  
associated in using shea fat as a cocoa fat substitute in chocolate (Lipp and Anklam, 1998) as  
well as in cosmetics (Hall *et al.*, 1996).

Shea fat has a relatively high economic value to the regions where it is grown and it  
is, therefore, unlikely to be intentionally produced as an animal feed. However, some

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3 1 downgraded or unwanted batches may become available occasionally to the animal feed  
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5 2 industry. Shea fat is also an important component of shea nut meal, the residue obtained  
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7 3 after fat extraction. Shea nut meal has the potential of becoming a useful non-conventional  
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9 4 feedstuff for animals (Atuahene *et al.*, 1998; Rhule, 1999). The meal has variable levels of  
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11 5 fat (30-360 g kg<sup>-1</sup> after oil extraction (Hall *et al.*, 1996)) due to the many different fat  
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13 6 extraction methods that may be used in the West African industry. The content of fat in the  
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15 7 meal may contribute a large proportion of its overall dietary available energy value. The  
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17 8 nutritional value of the varying amounts of residual fat in shea nut meal has not yet been  
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19 9 investigated.

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25 10 Shea fat is mostly comprised of saturated fats due to the presence of large amounts of  
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27 11 stearic acid but, unlike cocoa fat, it does not contain any significant amount of palmitic acid.  
28  
29 12 Even though there are detailed data on the fatty acid composition of shea fat (Lipp and  
30  
31 13 Anklam, 1998), there is a dearth of information on its digestibility and metabolisable energy  
32  
33 14 in farm animals. The specific objectives of this study were to compare the lipid digestibility  
34  
35 15 and metabolisable energy of shea fat with soya bean oil and cocoa fat when fed to broiler  
36  
37 16 chickens at three different inclusion levels (30, 60 and 90 g kg<sup>-1</sup>).

#### 38 39 40 41 MATERIALS AND METHODS

42  
43 18 Shea fat was supplied by Aarhus Ltd, Denmark, cocoa (*Theobroma cacao*) fat by Cadbury  
44  
45 19 Ltd, UK and soya bean oil by Target Feeds Ltd, UK. A basal diet was prepared that was  
46  
47 20 based on maize, dehulled soybean meal, wheat feed and fish meal, but no supplemental fat or  
48  
49 21 oil. Three dietary inclusion levels (30, 60, 90 g kg<sup>-1</sup>) of shea fat, cocoa fat and soybean oil  
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51 22 were added to the basal diet, which was calculated to contain adequate levels of required  
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53 23 nutrients for young broiler chickens (Table 1).

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57 24 Male d-old broiler chicks (Ross 308, UK) were reared in a litter floored pen and fed  
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59 25 on a proprietary broiler starter feed for 13 d. 160 birds were then randomly selected and two

1 birds placed into each of 80 metabolism cages (0.36 m x 0.36 m x 0.42 m) with wire floors,  
2 kept in an environmentally controlled room. Each cage of birds was fed one of the 10  
3 experimental diets for the following 8 d. Weight gains and feed intakes were recorded for the  
4 whole period and feed intakes were recorded and all egesta and excreta (droppings) were  
5 collected for the final 4 d. The droppings were collected daily and stored at 4°C until the  
6 total sample could be dried in a forced-draught oven at 88°C to constant weight. After  
7 drying, the droppings samples were ground in a laboratory mill fitted with 1mm-mesh size  
8 screen and then stored in a sealed container at 4°C prior to chemical analysis.

Table 1 near here

9 The lipid in the basal diet was obtained by continuous extraction of the prepared  
10 basal diet with light petroleum (b.p. 40-60°C) using a Soxtec system (920.39; AOAC, 2000).  
11 The sample of lipid from the basal diet plus the three test lipid samples were analysed for  
12 their fatty acid profiles (963.22; AOAC, 2000) using the one-step extraction and  
13 esterification procedure of Sukhija and Palmquist (1988). Fatty acid analysis was completed  
14 using a gas-liquid chromatograph (Perkin Elmer 8500; Perkin Elmer Life and Analytical  
15 Sciences Ltd, USA) fitted with an automatic sampler (Perkin Elmer AS 8300), integrator,  
16 and flame ionization detector. Fatty acids were identified by their relative retention times by  
17 comparison with retention times of known pure fatty acid standards (Sigma-Aldrich, UK).  
18 Free fatty acid, moisture content and peroxide value were determined using AOAC (2000)  
19 methods (940.28, 926.12, 965.33). The dry matter and lipid contents of the diets and  
20 droppings samples were determined using standard methods (934.01, 920.39; AOAC, 2000).

21 The experimental data were compared using a randomised block analysis of variance.  
22 Tier level of the cages was considered a blocking factor. Any experimental unit (a total of 6)  
23 that had measurements greater than three standard deviations from the treatment mean was  
24 omitted from the statistical analysis for all variables. Linear and non-linear regression  
25 techniques with grouping factors (fat or oil) were used to examine the effect of level of

1 dietary fat or oil addition on the lipid digestibility or determined AME respectively of the  
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1 dietary fat or oil addition on the lipid digestibility or determined AME respectively of the  
2 added lipids.

### 3 RESULTS

4 All three lipids (Table 2) had low free fatty acid and peroxide values. Thus, these fats met  
5 the suggested quality specifications for feed fats (Palmquist, 2002). The gross energy  
6 contents were typical of fats and oils. Shea fat contained predominantly stearic acid, while  
7 cocoa fat comprised mainly palmitic and stearic acids. The fatty acid profiles of the fats  
8 including soya bean oil in this study were typical of those reported in other studies (Banerji  
9 *et al.* 1984; Lipp and Anklam, 1998; Wiseman and Salvador, 1991). The lipid in the basal  
10 feed was comprised largely of unsaturated C:18, C:20 and C:22 fatty acids (Table 2). The  
11 presence of the long chain fatty acids was probably due to the fishmeal in the basal diet.  
12 Eicosapentaenoic acid (EPA, C:20:5n-3) and docosahexaenoic acid (DHA, C:22n-3) are  
13 found in fish oil (Hammershoj, 1995). Table 2 near here

14 Feed intake of birds fed soya bean oil compared to those fed shea and cocoa fats was  
15 affected neither by the lipid nor level of inclusion in the diets ( $P>0.05$ ). The gain-to-feed  
16 ratio was increased ( $P<0.001$ ) in the birds fed on the soya bean oil and there was a non-  
17 linear effect of concentration, with the greatest gain:feed ratio being obtained in the birds  
18 receiving the 60 g kg<sup>-1</sup> fat/oil additions. No lipid x level of inclusion interaction was  
19 observed ( $P>0.05$ ). Table 3 near here

20 The digestibility coefficients for the dry matter, lipid and gross energy of the shea  
21 and cocoa fats were lower than those for soya bean oil (Table 4). The 90 g kg<sup>-1</sup> level of lipid  
22 inclusion resulted in a decrease ( $P<0.01$ ) in lipid digestibility coefficients but there was also  
23 a lipid x level of inclusion interaction ( $P<0.01$ ) that was due to a very low digestibility  
24 coefficient of lipid (0.43) in the 90 g kg<sup>-1</sup> shea fat diet. There were no differences ( $P>0.05$ )

1 in lipid digestibility between the 30 g kg<sup>-1</sup> and 60 g kg<sup>-1</sup> inclusion levels for any of the three  
2 test lipids.

Table 4 near here

3 There was a significant effect of lipid source on AME of the diets ( $P<0.001$ ). The  
4 determined AME values of the soya bean oil diets were significantly ( $P<0.001$ ) greater than  
5 those of the shea and cocoa fat diets (Table 5). Increasing dietary lipid levels gave increasing  
6 ( $P<0.05$ ) determined AME values but there was a lipid x level interaction ( $P<0.05$ ). The  
7 increase in AME due to increasing lipid concentration occurred only up to 60 g kg<sup>-1</sup> for the  
8 shea and cocoa fat diets.

Tables 5 and 6 near here

## 9 DISCUSSION

10 The experimental data indicated that, in both shea and cocoa fat diets, there was a reduced  
11 AME in the 90 g kg<sup>-1</sup> diets. Although we considered it to be valid to examine this very high  
12 dietary level in the experiment, it is not of great practical significance. Practical poultry feeds  
13 typically contain a maximum of 50 g kg<sup>-1</sup> of added fats and practical problems of mechanical  
14 handling difficulties and pellet quality prevent greater amounts being added. Further  
15 examination of the data from this experiment could therefore either eliminate, or otherwise  
16 deal with the 90 g kg<sup>-1</sup> data, in order that conclusions can be made that are relevant to the  
17 commercial feed industry.

18 Linear regression analysis of the apparent lipid digestibilities of only the two lower  
19 inclusions (30 and 60 g kg<sup>-1</sup>) of the three diet series indicated that there was neither an  
20 inclusion-level effect nor a lipid x level interaction. Thus the derived mean digestibility of  
21 test lipids in the total lipid supply in the diets indicated lipid digestibility coefficients of 0.95,  
22 0.54 and 0.58 for soya bean oil, cocoa fat and shea fat respectively (Table 6). Wiseman *et al*  
23 (1991) indicated that lipid digestibility decreased when the overall dietary  
24 unsaturated:saturated fatty acid ratio decreased. In the present experiment, there was also a  
25 strong linear relationship ( $r^2=0.8792$ ) between the total dietary unsaturated:saturated fatty



1 acid ratio and lipid digestibility. However, this relationship was not always consistent within  
2 each dietary test lipid treatment, particularly in the soya oil treatment. This agrees with the  
3 curvilinear model described by Ketels and de Groot (1989). The estimate for soya bean oil  
4 is similar to the value determined by Mossab *et al.* (2000) for soya bean oil in chickens. No  
5 digestibility coefficients for cocoa fat appear to have been determined in poultry but the  
6 present estimate is similar to the coefficient of fat digestibility reported by Chen *et al.* (1989)  
7 from work with rats.

8         The lower fat digestibility of the shea and cocoa fat was expected. Wiseman and  
9 Salvador (1991) demonstrated that saturated fats had a lower digestibility than unsaturated.  
10 Stearic acid that is esterified at the 1-or-3-position on the glycerol moiety is released as free  
11 fatty acid in rats and, in the presence of calcium and magnesium, is poorly absorbed due to  
12 soap formation (Mattson *et al.*, 1979; Brink *et al.*, 1995). Both shea and cocoa fats have  
13 either C16:0 or C18:0 as the major fatty acids in the *sn*-1/3 position of the glycerol backbone  
14 (Lipp and Anklam, 1998).

15         The contribution of the added dietary lipid can be estimated by deduction of the  
16 determined AME of that diet from the determined AME of the basal feed (Nitsan *et al.*  
17 1997). The derived estimates for the three lipids used in the present experiment indicated  
18 AME concentrations of soya bean oil, cocoa fat and shea fat to be 39.8, 26.4 and  
19 22.0 MJ kg<sup>-1</sup> DM respectively (Table 6).

20         Prediction of the AME value of fats from the product of their apparent fat  
21 digestibility and gross energy concentration has been employed in a number of studies  
22 (Wiseman and Lessire, 1987). Wiseman (1990) observed that calculation of AME value of  
23 fat from its digestibility and gross energy tended to be lower than a directly determined  
24 AME. In the study, calculated AME values obtained by this method were 37.1, 21.5 and 23.1  
25 MJ kg<sup>-1</sup> DM for soya bean oil, cocoa fat and shea fat respectively with a standard error of

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3 1 1.18 MJkg<sup>-1</sup>. The values for soya bean oil and cocoa fat were both lower than the determined  
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6 2 values, but the calculated shea fat value was numerically larger. The data therefore indicate  
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8 3 that the utilisation of the absorbed lipid hydrolysis products from shea fat may be poorer  
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10 4 than expected or the dietary shea fat may have influenced the availability of other nutrients  
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12 5 of the diet.

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15 6 In conclusion, the present study has shown that shea fat contributes to the energy  
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17 7 supply to a broiler chicken feed although it had a poor digestibility at high (90 g kg<sup>-1</sup>) dietary  
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19 8 concentration. The derived AME for shea fat of 22.0 MJ kg<sup>-1</sup> DM gives a valid estimate of its  
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21 9 energy concentration at dietary concentrations of 60 g kg<sup>-1</sup> or less.

#### 22 10 REFERENCES

- 23  
24  
25 11 ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, AOAC (2000). Official  
26  
27 12 methods of analysis. 17<sup>th</sup> edition. Association of Official Analytical Chemists, Washington,  
28  
29 13 D.C.  
30  
31 14 ATUAHENE, C.C., DONKOH, A. and ASANTE, F. (1998). Value of sheanut cake as a  
32  
33 15 dietary ingredient for broiler chicken. *Animal Feed Science and Technology* 72:133-142.  
34  
35 16 BANERJI, R., CHOWDHURY, A.R., MISRA, G. and NIGAM, S.K. (1984). Butter from  
36  
37 17 plants. *Fette, Seifen, Anstrichmittel* 86:279-284.  
38  
39 18 BRINK, E.J., HADDEMAN, E., de FOUW, N.J. and WESTSTRATE, J.A. (1995).  
40  
41 19 Positional distribution of stearic acid and oleic acid in a triacylglycerol and dietary calcium  
42  
43 20 concentration determines the apparent absorption of these fatty acids in rats. *Journal of*  
44  
45 21 *Nutrition* 125: 2379-2387.  
46  
47 22 CHEN, I.S., SUBRAMANIAM, S., VAHOUNY G.V., CASSIDY, M.M., IKEDA, I. and  
48  
49 23 KRITCHEVSKY, D.A. (1989). Comparison of the digestion and absorption of cocoa butter  
50  
51 24 and palm kernel oil and their effects on cholesterol absorption in rats. *Journal of Nutrition*  
52  
53 25 *119: 1569-1573.*

- 1  
2  
3 1 HALL, J.B., AEBISCHER, D.P., TOMLINSON, H.F., OSEI-AMANING, E. and HINDLE,  
4  
5 2 J.R. (1996). *Vitellaria paradoxa*: a monograph. School of Agricultural and Forest Sciences  
6  
7 3 Publication No. 8, University of Wales, Bangor. 105 pp.  
8  
9  
10 4 HAMMERSHOJ, M. (1995). The effect of dietary fish oil (*Ammodytes spp*) on fatty acid  
11  
12 5 composition, fat content and colour of yolk and egg quality of hen eggs. *Proceedings, Lipids*  
13  
14 6 *in Animal Nutrition, Lipid Forum*, Danish Institute of Animal Science, Tjele, Denmark, p.  
15  
16 7 19.  
17  
18 8 KETELS, E. and de GROOTE, G. (1989). Effect of ratio of unsaturated to saturated fatty  
19  
20 9 acids of the dietary lipid fraction on utilisation and metabolisable energy of added fats in  
21  
22 10 young chicks. *Poultry Science* 68: 1506-1512.  
23  
24  
25 11 LEAKEY, R.R.B. 1999. Potential for novel food products from agroforestry trees: a review.  
26  
27 12 *Food Chemistry* 66: 1-14  
28  
29  
30 13 LIPP, M. and ANKLAM, E. (1998). Review of cocoa butter and alternative fats for use in  
31  
32 14 chocolate-Part A. Compositional data. *Food Chemistry* 62: 73-97.  
33  
34  
35 15 MATTSON, F.H., NOLEN, G.A. and WEBB, M.R. (1979). The absorbability by rats of  
36  
37 16 various triglycerides of stearic and oleic acid and the effect of dietary calcium and  
38  
39 17 magnesium. *Journal of Nutrition* 109: 1682-1687.  
40  
41  
42 18 MOSSAB, A., HALLOUIS, I. J. M. and LESSIRE, M. (2000). Utilization of soybean oil and  
43  
44 19 tallow in young turkeys compared with young chickens. *Poultry Science* 79:1326-1331.  
45  
46  
47 20 NITSAN, Z., DVORIN, A., ZOREF, Z. and MOKADY, S. (1997). Effect of added soya  
48  
49 21 bean oil and dietary energy on metabolisable and net energy of broiler diets. *British Poultry*  
50  
51 22 *Science* 38: 101-106.  
52  
53  
54 23 PALMQUIST, D.L. (2002). An appraisal of fats and fatty acids. In: *Poultry Feedstuffs:*  
55  
56 24 *Supply, Composition and Nutritive Value* (eds. J.M. McNab and K.N. Boorman), pp. 87-97,  
57  
58 25 CAB International, Wallingford, UK.  
59  
60

- 1  
2  
3 1 RHULE, S.W.A. (1999). Performance of pigs on diets containing detoxified sheanut cake.  
4  
5  
6 2 *Tropical Animal Health and Production* 31: 45-53.  
7  
8 3 SUKHIJA, P.S. and PALMQUIST, D.L. (1988). Rapid method for determination of total  
9  
10 4 fatty acid content and composition of feedstuffs and feces. *Journal of Agricultural and Food*  
11  
12 5 *Chemistry* 36: 1202-1206.  
13  
14  
15 6 WISEMAN, J. and LESSIRE, M. (1987). Interactions between fats of differing chemical  
16  
17 7 content: apparent metabolisable energy values and apparent fats availability. *British Poultry*  
18  
19 8 *Science* 28: 663-676.  
20  
21  
22 9 WISEMAN, J. (1990). Variability in the nutritive value of fats for non-ruminants. In:  
23  
24 10 Feedstuff evaluation (ed. J. Wiseman and D.J.A Cole), pp. 215-234. Butterworths, London.  
25  
26  
27 11 WISEMAN, J. and SALVADOR, F (1991). The influence of free fatty acid content and  
28  
29 12 degree of saturation on the apparent metabolisable energy value of fats fed to broilers.  
30  
31 13 *Poultry Science* 70: 573-582.  
32  
33  
34 14 WISEMAN, J., SALVADOR, F. and CRAIGON, J. (1991). Prediction of the apparent  
35  
36 15 metabolizable energy content of fats fed to broiler chickens. *Poultry Science* 70: 1527-1533.  
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**Table 1.** *Calculated composition (g kg<sup>-1</sup>) of the basal diet*

Ingredients	Amount (g kg <sup>-1</sup> )
Maize	400
Dehulled soya bean meal	300
Fishmeal	30
Wheatfeed	220
Lysine (HCl)	3
Methionine	4
Limestone	4
Dicalcium phosphate	13
Vitamin and trace element premix*	22
Salt	4
<i>Calculated composition (g kg<sup>-1</sup>)</i>	
Crude protein	239.4
Crude fibre	36.9
Calcium	11.4
Phosphorus	7.6
Sodium	2.0
Lysine	15.2
Methionine	7.6
Methionine + Cystine	11.6
ME (MJ kg <sup>-1</sup> )**	11.5

\*Vitamin-trace mineral premix for broilers (Ian Hollows Feed Supplement, UK) added per kg:

800 mg retinol, 150 mg cholecalciferol, 1.25 g tocopherol, 150 mg thiamin, 500 mg riboflavin, 150 mg pyridoxine, 750 mg cyanocobalamin, 3 g nicotinamide, 0.5 g pantothenic acid, 75 mg folic acid, 6.25 g biotin, 12.5 g choline chloride, iron 1 g, 50 mg cobalt, 5 g manganese, 0.5 g copper, 4 g zinc, 50 mg iodine, 10 mg selenium, and 25 mg molybdenum.

\*\*ME calculated using soya bean oil ME (36.5 MJ kg<sup>-1</sup>).

Determined crude fat (g kg<sup>-1</sup> DM) contents of diets with added lipid at 30, 60 and 90 g kg<sup>-1</sup> including basal diet were: basal diet (26.9); soya bean oil diets (50.1, 78.8, 102.5); cocoa fat diets (51.1, 77.1, 108.6); and shea fat diets (50.0, 76.9, 97.2).

**Table 2.** Composition of test lipids and oil extracted from the basal diet

	*Oil in basal diet	Soya bean oil	Cocoa fat	Shea fat
Relative proportions of fatty acids (g kg <sup>-1</sup> )				
Myristic acid (**C <sub>14:0</sub> )	5.5	0.0	0.0	0.0
Pentadecanoic acid (C <sub>15:0</sub> )	0.0	0.0	0.0	1.5
Palmitic acid (C <sub>16:0</sub> )	151.7	110.6	259.3	35.6
Palmitoleic acid (C <sub>16:1</sub> )	8.7	0.0	2.9	0.0
Heptadecanoic acid (C <sub>17:0</sub> )	1.2	1.0	1.8	0.0
Stearic acid (C <sub>18:0</sub> )	24.4	36.2	377.4	430.6
Oleic acid (C <sub>18:1</sub> )	253.8	227.1	341.9	449.8
Linoleic acid (C <sub>18:2</sub> )	466.2	546.2	3.1	63.8
Linolenic acid (C <sub>18:3</sub> )	39.3	69.4	1.9	0.0
Arachidic acid (C <sub>20:0</sub> )	4.2	3.3	11.7	15.1
Erucic acid (C <sub>20:1</sub> )	13.0	2.7	0.0	3.6
Eicosapentaenoic acid (C <sub>20:5</sub> )	10.1	4.4	0.0	0.0
Cetoleic acid (C <sub>22:1</sub> )	10.4	0.0	0.0	0.0
Docosahexaenoic acid (C <sub>22:6</sub> )	12.9	0.0	0.0	0.0
Total unsaturated fatty acids	814.4	849.8	349.8	517.2
Total saturated fatty acids	187	151.1	650.2	482.8
Unsaturated/saturated fatty acid ratio	4.36	5.62	0.54	1.07
Moisture (g kg <sup>-1</sup> )	nd	0.0	0.0	0.0
Free fatty acids (g kg <sup>-1</sup> )	nd	13.0	14.0	2.0
Peroxide value (meq kg <sup>-1</sup> )	nd	0.26	0.08	0.13
Gross energy (MJ kg <sup>-1</sup> )	37.54	39.20	39.82	39.93

\*Oil extracted from the basal diet    \*\*Carbon chain length followed by number of double bonds

nd = not determined

**Table 3.** Growth performance of broiler chickens (13-21d) fed 3 lipids at 3 levels

Variable	Lipid level (g kg <sup>-1</sup> )	Test lipids			mean	Analysis of variance		
		Soya bean oil	Cocoa fat	Shea fat		Factor	SED <i>r.d.f.</i> =56	<i>P</i>
Mean feed intake (g/bird.day)	0				68.6	Lipids	2.479	0.141
	30	67.0	69.5	67.9	68.2	Level	2.479	0.588
	60	69.8	70.3	71.7	70.6			
	90	64.1	71.9	72.2	69.4			
mean		67.0	70.6	70.6	69.4	Lipids x Level	3.036	0.222
Mean live weight gain (g/bird.day)	0				41.2	Lipids	1.945	0.674
	30	42.2	41.1	41.1	41.5	Level	1.945	0.183
	60	46.9	42.0	43.8	44.2			
	90	41.2	42.4	41.3	41.6			
mean		43.4	41.8	42.1	42.4	Lipids x Level	2.382	0.346
Gain : Feed	0				0.61	Lipids	0.0133	<0.001
	30	0.63	0.59	0.60	0.61	Level	0.0133	0.037 0.433 (L) 0.020 (Q)
	60	0.67	0.60	0.61	0.63			
	90	0.64	0.59	0.57	0.60			
mean		0.65	0.59	0.60	0.61	Lipids x Level	0.0162	0.139

Polynomial contrasts: *L*-linear effects, *Q*-quadratic effects, *SED*-standard error of difference, *P*-probability, *r.d.f.*-residual degrees of freedom.

**Table 4.** Apparent metabolisability of dietary dry matter, lipid and gross energy in broiler chickens (13-21d) fed 3 lipids at 3 levels

Variable	Lipid level (g kg <sup>-1</sup> )	Test lipids			mean	Analysis of variance		
		Soya bean oil	Cocoa fat	Shea fat		Factor	SED <i>r.d.f.</i> =56	<i>P</i>
Dry matter	0				0.64	Lipids	0.00714	<0.001
	30	0.66	0.64	0.64	0.65	Level	0.00714	0.002
	60	0.67	0.63	0.64	0.65			
	90	0.65	0.63	0.61	0.63	Lipids x Level	0.00874	0.024
mean		0.66	0.63	0.63	0.64			0.144(L)
Lipid	0				0.72	Lipids	0.02895	<0.001
	30	0.85	0.63	0.64	0.71	Level	0.02895	<0.001
	60	0.87	0.59	0.62	0.69			
	90	0.80	0.56	0.43	0.60	Lipids x Level	0.03545	0.003
mean		0.84	0.59	0.57	0.67			0.019(L)
Gross energy	0				0.68	Lipids	0.01082	<0.001
	30	0.71	0.68	0.67	0.69	Level	0.01082	<0.001
	60	0.72	0.67	0.68	0.69			
	90	0.70	0.64	0.63	0.66	Lipids x Level	0.01031	0.019
mean		0.71	0.66	0.66	0.68			0.065(L)

*SED*-standard error of difference, *P*-probability, *r.d.f.*- residual degrees of freedom.

Polynomial contrasts for lipid x level interaction: *L*-linear effects.



**Table 5.** *Determined AME of experimental diets*

Variable	Lipid level (g kg <sup>-1</sup> )	Test lipids			mean	Analysis of variance		
		Soya bean oil	Cocoa fat	Shea fat		Factor	SED <i>r.d.f.</i> =56	<i>P</i>
AME	0				12.43	Lipids	0.1635	<0.001
(MJ kg <sup>-1</sup> DM)	30	13.28	12.87	12.57	12.91	Level	0.1635	0.001
	60	13.96	13.10	13.08	13.38			
	90	13.94	12.64	12.55	13.04	Lipids x Level	0.2003	0.015
mean		13.73	12.87	12.73	13.11			0.026(L)

*SED*-standard error of difference, *P*-probability, *r.d.f.*- residual degrees of freedom.

*Polynomial contrasts for lipid x level interaction: L-linear effects.*

**Table 6.** Apparent lipid digestibility and AME estimates of soya bean oil, shea fat and cocoa fat at 2 lipid levels (30, 60 g kg<sup>-1</sup>)

Test lipids	30 g kg <sup>-1</sup>	60 g kg <sup>-1</sup>	Mean
Digestibility coefficient			
Soya bean oil	0.96	0.93	0.95
Cocoa fat	0.55	0.53	0.54
Shea fat	0.58	0.58	0.58
AME (MJ kg <sup>-1</sup> DM)			
Soya bean oil	42.0	37.6	39.8
Cocoa fat	29.5	23.3	26.4
Shea fat	21.2	22.7	22.0