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Utilization of fat and fatty acids and energetic feed value (AME_N, TME_N) of several fat types for laying hens

Sven Dänicke and Ingrid Halle [1]

Abstract

The aim of the present study was to evaluate the fat and fatty acid utilization as well as the energetic feed value of palm oil, coconut oil, peanut oil, olive oil, beef tallow, soybean oil, safflower oil and beef tallow-soybean oil blend (50:50) for laying hens.

Balance experiments were performed with Lohmann Brown laying hybrids (26.-36. week of age) according to a multi-level assay which consisted of testing a low-fat diet (0.32 % crude fat) alone and of the low-fat diet successively substituted by the fat type under test (50, 100 and 150 $g \cdot kg^{-1}$).

Results of the balance studies were regressively evaluated to yield both apparent and true utilization values of the different fat types. AME_N-contents ($MJ \cdot kg^{-1}$), apparent utilization (%) of crude fat and total fatty acids of palm oil, coconut oil, peanut oil, olive oil, beef tallow, soybean oil, safflower oil and beef tallow-soybean oil blend (50:50) were: 20.0, 55.4, 67.0; 32.1, 87.5, 89.3; 38.1, 92.7, 96.0; 36.3, 94.2, 96.7; 28.4, 70.7, 75.7; 35.6, 93.8, 95.6, 38.0, 95.7, 97.5 and 32.2, 84.8, 87.8; respectively.

True utilization of fat and fatty acids as well as TME-values were only slightly higher than the corresponding apparent figures.

Endogenous fat losses were estimated to be in a range between 2.1 $g \cdot kg^{-1}$ and 5.5 $g \cdot kg^{-1}$ diet corresponding to 136 $mg \cdot d^{-1} \cdot W^{-0.75}$ and 356 $mg \cdot d^{-1} \cdot W^{-0.75}$.

Keywords: Laying hen, AME_N, dietary fat type, fatty acid utilization, endogenous fat losses

Zusammenfassung

Verwertung von Fett und Fettsäuren sowie energetischer Futterwert (AME_N, TME_N) verschiedener Fettarten bei Legehennen

Das Ziel der vorliegenden Studie bestand in der Ermittlung der Fett- und Fettsäurenverwertung sowie des energetischen Futterwertes von Palmfett, Kokosfett, Erdnussöl, Olivenöl, Rindertalg, Sojaöl, Distelöl sowie einer Mischung aus Rindertalg und Sojaöl (50:50) bei Legehennen.

Es wurden Bilanzversuche mit Lohmann Brown-Legehybriden (26.-36. Woche) nach einem "multi-level assay" durchgeführt. Dabei wurde eine nahezu fettfreie Basaldiät (0,32 % Rohfett) allein sowie die durch die verschiedenen Fette schrittweise substituierte Basaldiät (50, 100 and 150 $g \cdot kg^{-1}$) geprüft.

Die Ergebnisse der Bilanzversuche wurden regressiv ausgewertet, um Aussagen zu scheinbaren und wahren Verwertungsmaßen zu treffen. Die AME_N ($MJ \cdot kg^{-1}$) sowie die scheinbare Verwertung (%) des Rohfettes sowie der gesamten Fettsäuren betrugen 20,0; 55,4 und 67,0 für Palmfett, 32,1; 87,5 und 89,3 für Kokosfett; 38,1; 92,7 und 96,0 für Erdnussöl; 36,3; 94,2 und 96,7 für Olivenöl; 28,4; 70,7 und 75,7 für Rindertalg; 35,6; 93,8 und 95,6 für Sojaöl; 38,0; 95,7 und 97,5 für Distelöl sowie 32,2; 84,8 und 87,8 für eine Mischung aus Rindertalg und Sojaöl (50:50).

Die wahre Verwertung des Rohfettes und der Fettsäuren sowie die TME waren nur geringfügig höher als die korrespondierenden scheinbaren Maße.

Die endogenen Fettverluste sind in einem Bereich von 2,1 $g \cdot kg^{-1}$ bis 5.5 $g \cdot kg^{-1}$ Futter zu erwarten. Bezogen auf die metabolische Körpermasse ergibt sich ein Bereich zwischen 136 $mg \cdot d^{-1} \cdot W^{-0.75}$ und 356 $mg \cdot d^{-1} \cdot W^{-0.75}$.

Schlüsselwörter: Legehenne, AME_N, Futterfett, Fettsäurenverwertung, endogene Fettverluste

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1 Introduction

It is well-known that fatty acid composition of egg yolk can be markedly influenced by dietary fats, mainly via direct incorporation of dietary fatty acids (for literature review see Halle, 1996). However, it becomes clear from these reviews that the same fatty acids from different fat types are incorporated with different efficiencies. It might be deduced that differences in apparent digestibility of fatty acids originating from different fats might be responsible. In addition, metabolic losses of fat and fatty acids might modify the true digestibility or absorbability values. However, estimation of metabolic fat losses and absorbability of fat has only been considered in a few studies (e. g. Carew et al., 1972; Veen et al., 1974).

Moreover, apparent fat and fatty acid digestibility, or more correctly utilization or availability, and energetic feed values of different fat types were mainly determined using broilers or cocks. Therefore, the aim of the present study was to determine apparent and true utilization of fat and fatty acids by laying hens - including metabolic losses of fat and fatty acids - from fat types differing markedly in fatty acid composition as well as the energetic feed value of those fats (AME_N, TME_N) by a multi-level assay as suggested by several authors (e. g. Wiseman and Lessire, 1987; Ketels and De Groote, 1989; Wiseman and Salvador, 1989).

2 Material and methods

2.1 Experimental design

Feed values of different fat types (AME_N-contents and apparent and true utilization of fat and fatty acids of palm oil, coconut oil, peanut oil, olive oil, beef tallow[2], soybean oil, safflower oil, beef tallow-soybean oil blend) were estimated by a multi-level assay. This consisted of testing a low-fat diet and a diet in which different fat types were substituted in stages in a low fat diet (50, 100 and 150 g of the low-fat diet were substituted by the respective fats) and the subsequent regressive evaluation (see below) of the experimental results. Composition of the low fat diet and fatty acid composition of the tested fats are shown in Table 1 and 2, respectively.

Table 1.
Composition of low-fat basal diet (%)

Components:	
Maize starch	51.75
Soybean meal	13.00
Wheat gluten	11.47
Cellulose	11.00
Limestone	6.60
Di-calciumphosphate	3.81
Sodium chloride	0.64
L-lysine HCL	0.45
Methionine	0.28
Premix [1]	1.00
Composition:	
Crude protein [2]	15.60
Crude fat [2]	0.32
AME_N (MJ/kg) [3]	10.50
Lysine [3]	0.85
Methionine + cystine [3]	0.79
Methionine [3]	0.50
Calcium [3]	3.43
Total phosphorus [3]	0.80
Sodium[3]	0.25

[1] provided per kg diet: Fe, 25 mg; Cu, 5 mg; Zn, 75 mg; Mn, 60 mg; Se, 0.1 mg; I, 0.5 mg; Co, 0.1 mg; vitamin A, 10000 IU; vitamin D3, 2000 IU; vitamin E, 20 mg; vitamin K, 2.5 mg, vitamin B1, 1 mg; vitamin B2, 4 mg; vitamin B6, 3 mg; vitamin B12, 10 mg; pantothenic acid, 10 mg; nicotinic acid, 25 mg; biotin, 102 mg; folic acid, 0.75 mg; choline chloride, 400 mg; BHT, 120 mg
[2] analyzed values
[3] calculated values

[2] Experiments were performed before 1st of December of 2000

Table 2.
Fatty acid composition of tested fat types (as % of sum of main fatty acids)

	Lauric acid (C12:0)	Myristic acid (C14:0)	Palmitic acid (C16:0)	Stearic acid (C18:0)	Oleic acid (C18:1)	Linoleic acid, n-6 (C18:2)	Linolenic acid, n-3 (C18:3)
Palm oil			46.3	8.3	37.3	7.9	0.1
Coconut oil	47.4	19.5	12.0	5.6	12.7	2.9	
Peanut oil			12.1	5.6	58.5	23.8	
Olive oil				1.1	88.3	7.0	3.6
Beef tallow		6.1	31.7	25.6	34.1	2.3	0.3
Soybean oil			10.8	3.6	28.0	50.1	7.4
Safflower oil			8.8	4.9	9.7	76.5	0.1
Beef tallow-soybean oil blend		2.7	21.2	14.6	30.2	27.7	3.7

3 Balance experiments

A total of 35 Lohmann Brown laying hybrids were used in the balance experiments. Hens were placed into single metabolic cages at the age of 22 weeks and were fed a commercial laying hen diet. The light period was increased stepwise up to 16 h light daily and then maintained at this level. Room temperature and relative humidity were regulated at 18 °C and 60 %, respectively. Experimental diets were introduced when the hens were 26 weeks old. Mean body weight was 1760 g ±106 g at that time. Two fat types (5 hens per diet) were tested in each balance experiment and 5 consecutive balance experiments were performed in order to test all fat types and the low-fat diet (10 hens). Each balance experiment consisted of a 14-day pre-experimental period and the following 5-day-collection period. Hens were adapted to the experimental diets during the pre-experimental period and to a daily feed amount of 100 g per hen. Feed was given twice daily in two equal portions during both experimental periods. Excreta were totally collected during the collection period twice daily and kept frozen between collections. Water was offered for ad libitum consumption.

4 Sample preparation

Frozen excreta samples were freeze dried. Diet samples and freeze dried excreta samples were finely ground to pass through a 1mm screen.

5 Analysis

Crude fat of diets and of freeze-dried excreta were analyzed according to the methods of the VDLUFA (Naumann and Bassler, 1993) by extraction with chloroform-methanol following acidification with 6 N HCl. Fatty acids of the fat extracts were methylated with trimethylsulfoniumhydroxide and the resulting methyl esters were identified from their retention time using a gas chromatography system which consists of the HP 5890 gas-chromatograph, the HP 7673 autosampler and the HP 3365 data-station. The FFAP-fused silica column used for separation had a length of 30 m and an inner diameter of 0.53 mm. Helium was used as carrier gas with a flow of 9 ml/min. A flame ionisation detector was used for detection of the fatty acids.

Gross energy of diets and of freeze dried excreta samples were measured using an adiabatic bomb calorimeter (model C 4000, Heitersheim, Germany).

6 Calculations and statistics

Generally, apparent utilization of fat and fatty acids as well as AME-contents of experimental diets were calculated according to the total collection method, i.e., by the difference between total quantities ingested and excreted by the hens. AME-contents were corrected for a zero-N-balance using a factor of 36.5 kJ/g N-retention (Titus et al., 1956) to yield the AME_N-contents of the diets. Moreover, AME_N-contents of the pure fats were calculated according to the substitution or difference method taking the fat inclusion level and the AME_N-content determined for the low-fat diet into account.

A eight by three 2-factorial design of analysis of variance (ANOVA) was applied for evaluation of parameters calculated for the experimental diets (AME_N-contents, apparent utilization of dietary fat and fatty acids):

$$y_{ijk} = \mu + a_i + b_j + (axb)_{ij} + e_{ijk}$$

where

y_{ijk} = k^{th} hen subjected to fat type i and fat dose j,
a_i = fat type (palm oil, coconut oil, peanut oil, olive oil, beef tallow, soybean oil, safflower oil, beef tallow-soybean oil blend),
b_j = fat dose (50 g/kg, 100 g/kg, 150 g/kg),
$(axb)_{ij}$ = interactions between a_i and b_j,
e_{ijk} = error term

In addition, orthogonal effects (linear and quadratic effects) of fat doses were checked.

Results are given as mean values along with the probabilities for all tested effects and pooled standard error of means.

Multiple linear regression analysis was performed in order to estimate the AME_N-contents and the apparent and true utilization of the pure fats and their fatty acids according to the following model:

$$y = a + b1 \cdot s1 \cdot x + b2 \cdot s2 \cdot x + b3 \cdot s3 \cdot x + b4 \cdot s4 \cdot x + b5 \cdot s5 \cdot x + b6 \cdot s6 \cdot x + b7 \cdot s7 \cdot x + b8 \cdot s8 \cdot x$$

where

y is dietary AME_N-content or the amount of utilized fat or fatty acid (g per kg of diet);
x is the amount of ingested fat or fatty acid (g per kg of diet);
b1...b8 are the fat-specific slopes (b1=palm oil, b2=coconut oil, b3=peanut oil, b4=olive oil, b5=beef tallow, b6=soybean oil, b7=safflower oil, b8=beef tallow-soybean oil blend) which are “switched on or off” by their respective switch-variables (s1...s8, zero or one, respectively).

Basal low-fat diet is “switched on” for estimation of all “b”-parameters which also means that the intercept on ordinate (parameter “a”) is estimated simultaneously by all diets whereas the particular slopes for a given fat type are estimated by the respective dose-response-relationship (corresponding values for the low-fat diet and the diets containing 50, 100 and 150 g/kg of that particular fat).

Table 3.
Effect of different fat types and different levels of inclusion on utilization of fat and fatty acids (n=5)

Fat type	Dose (g/kg)	Apparent utilization (%)							
		Crude fat	Lauric acid (C12:0)	Myristic acid (C14:0)	Palmitic acid (C16:0)	Stearic acid (C18:0)	Oleic acid (C18:1)	Linoleic acid (C18:2 n-6)	Linolenic acid (C18:3 n-3)
Palm oil	...	56.2			61.7	72.8	80.0	69.6	
Coconut oil	...	84.2	95.6	88.4	75.0	72.7	91.7	62.3	
Peanut oil	...	91.3			93.0	93.2	97.9	94.8	
Olive oil	...	91.7				82.4	97.6	84.4	97.7
Beef tallow (T)	...	69.6		94.2	71.4	55.6	93.4	68.3	
Soybean oil (S)	...	91.2			90.1	77.8	96.5	96.6	98.2
Safflower oil	...	93.3			94.4	94.2	95.2	98.5	
S:T = 50:50	...	82.8		96.5	80.0	59.5	94.3	97.1	98.5
Palm oil	50	59.1			67.2	74.4	85.1	68.1	
Coconut oil	50	80.0	96.8	91.3	67.7	74.3	85.8	33.2	
Peanut oil	50	91.4			92.6	93.2	98.3	94.9	
Olive oil	50	89.1				76.0	97.6	76.0	96.5
Beef tallow (T)	50	67.2		94.4	71.0	56.7	93.0	53.4	
Soybean oil (S)	50	87.9			83.0	59.3	96.4	96.7	98.1
Safflower oil	50	90.3			89.5	91.0	92.7	98.3	
S:T = 50:50	50	79.5		96.2	77.2	51.9	94.0	96.3	98.0
Palm oil	100	57.4			62.7	74.2	81.3	71.3	
Coconut oil	100	84.9	95.1	86.7	75.9	72.5	93.8	71.5	
Peanut oil	100	90.3			93.0	92.7	97.6	94.1	
Olive oil	100	92.3				79.8	97.4	86.6	98.0
Beef tallow (T)	100	73.8		93.9	73.0	57.2	93.9	70.3	
Soybean oil (S)	100	92.2			90.8	84.3	96.2	96.3	98.0
Safflower oil	100	94.8			95.2	95.4	96.5	98.9	
S:T = 50:50	100	85.8		96.8	82.3	60.8	95.6	98.4	99.0
Palm oil	150	52.2			55.3	69.9	73.7	69.6	
Coconut oil	150	87.8	94.9	87.1	81.4	71.3	95.5	82.4	
Peanut oil	150	92.1			93.3	93.6	97.7	95.4	
Olive oil	150	93.7				91.4	97.8	90.5	98.6
Beef tallow (T)	150	67.9		94.1	70.3	52.8	93.4	81.1	
Soybean oil (S)	150	93.4			93.6	90.0	96.9	96.7	98.4
Safflower oil	150	94.9			95.9	96.2	96.3	98.4	
S:T = 50:50	150	83.1		96.6	80.6	65.7	93.3	96.5	98.5
Probability									
Dose		0.066	0.276	0.471	0.156	0.059	0.437	<0.001	<0.001
Linear		0.085	0.149	0.315	0.111	0.021	0.834	<0.001	<0.001
Quadratic		0.091	0.492	0.484	0.232	0.497	0.202	0.066	0.032
Fat type		<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Dose x fat type		0.572		0.487	0.120	0.233	0.002	<0.001	<0.001
PSEM		2.7	.8	1.5	3.3	5.2	1.8	3.5	0.2

Table 4.
Effect of different fat types and different levels of inclusion on metabolizability of gross energy and AME_N-concentration of diets and of fats calculated according to the difference-method (n=5)

Fat type	Dose (g/kg)	Diets		Fat	
		AME_N/ GE (%)	AME_N (MJ/kg)	AME_N/ GE (%)[1]	AME_N (MJ/kg)
Palm oil	...	70.7	11.67	51.1	20.09
Coconut oil	...	79.7	12.88	83.8	31.49
Peanut oil	...	83.4	13.68	108.9	42.89
Olive oil	...	81.7	13.41	97.6	38.34
Beef tallow (T)	...	76.1	12.64	79.1	31.23
Soybean oil (S)	...	80.7	13.43	101.3	39.82
Safflower oil	...	82.2	13.65	106.2	41.74
S:T = 50:50	...	79.2	13.09	93.1	36.67
Palm oil	50	72.5	11.12	50.0	19.66
Coconut oil	50	76.1	11.49	72.0	27.07
Peanut oil	50	83.6	12.74	131.9	51.98
Olive oil	50	80.1	12.10	99.9	39.25
Beef tallow (T)	50	77.0	11.81	84.6	33.41
Soybean oil (S)	50	79.2	12.37	113.6	44.63
Safflower oil	50	80.4	12.45	117.6	46.20
S:T = 50:50	50	79.2	12.25	107.4	42.31
Palm oil	100	69.0	11.37	45.0	17.69
Coconut oil	100	79.9	12.87	86.8	32.65
Peanut oil	100	81.2	13.34	94.9	37.38
Olive oil	100	81.5	13.43	97.4	38.28
Beef tallow (T)	100	76.6	12.80	80.8	31.93
Soybean oil (S)	100	81.2	13.56	100.8	39.60
Safflower oil	100	82.5	13.66	103.2	40.56
S:T = 50:50	100	79.8	13.21	91.5	36.05
Palm oil	150	70.7	12.51	58.4	22.93
Coconut oil	150	83.0	14.28	92.4	34.75
Peanut oil	150	85.3	14.97	99.8	39.32
Olive oil	150	83.3	14.69	95.4	37.49
Beef tallow (T)	150	74.8	13.32	71.8	28.35
Soybean oil (S)	150	81.5	14.35	89.6	35.22
Safflower oil	150	83.7	14.84	97.9	38.47
S:T = 50:50	150	78.4	13.82	80.3	31.64
Probability					
Dose		0.053	<0.001	0.001	0.001
Linear		0.022	<0.001	<0.001	<0.001
Quadratic		0.545	0.684	0.155	0.150
Fat type		<0.001	<0.001	<0.001	<0.001
Dose x fat type		0.031	0.025	0.002	0.002
PSEM		1.4	0.2	6.1	2.37

[1] Calculated as the ratio between AME_N-concentration of fat and gross energy concentration of fat (for gross energy concentrations of fat types see Table 7)

AME_N-contents and utilization values for the particular fats were then obtained by extrapolating to a dietary fat content of 1000 g/kg (e.g. Muztar et al., 1981; Wiseman et al., 1986; Wiseman and Lessire, 1987). Moreover, the intercept on ordinate gives an estimate for a fat-free diet which should be close to the tested low-fat diet.

True utilization values of fats and fatty acids were estimated using the same regression model but where y is the fat or fatty acid excretion ($g \cdot d^{-1} \cdot kg$ body $weight^{-0.75}$) and x is the fat or fatty acid intake ($g \cdot d^{-1} \cdot kg$ body $weight^{-0.75}$). True utilization values for fat and fatty acids can be deduced from the respective regression slopes using the relationship: $(1-b) \cdot 100$ (Veen et al., 1974). Moreover, the intercepts on ordinate produce estimates for metabolic fat or fatty acid excretion.

Data were fitted to the regression models using the iterative Quasi-Newton-procedure of the Statistica for the Windows™ operating system (StatSoft Inc., 1994)[8] and the Σ(observed value-predicted value)² as loss function.

All other statistics were also carried out using this software-package.

7 Results

7.1 Balance experiments

Balance experiments took a normal course. All hens were laying during the balance experiments (laying intensity >80 %).

Apparent utilization of crude fat and fatty acids are given in Table 3. Fat type significantly influenced fat utilization whereas for the level of fat inclusion (dose) only a trend (p=0.066) was detected. Similarly, linear and quadratic effects of dose were ascertained only as tendencies (p=0.085 and p=0.091, respectively). No significant interactions between fat type and level of fat inclusion were found. Utilization values for fatty acids were only calculated for those fatty acids which were present in diets in significant quantities (see Table 2). For this reason, utilization of lauric acid (C12:0) could be evaluated for coconut oil only. No dose effect was observed for this fatty acid. Utilization values for myristic acid (C14:0) were calculated for coconut oil, beef tallow and the blend of beef tallow with soybean oil. Utilization of palmitic acid (C16:0) could be calculated for all tested fat types with the exception of olive oil. For the utilization of the latter two fatty acids similar significance relations were detected for main effects and interactions as described for crude fat utilization. Utilization of stearic acid (C18:0), oleic acid (C18:1) and linoleic acid (C18:2 n-6) were evaluated for all fat types whereas utilization of linolenic acid (C18:3 n-3) was calculated for olive oil, soybean oil and the fat blend only. Significant fat type effects were detected for these fatty acids whereas significant dose effects and orthogonal effects were found for the polyunsaturated linoleic and linolenic acid. In addition, significant interactions between level of fat inclusion and fat type were observed for all fatty acids of the C18-family which indicates that fat dose affected the utilization of these fatty acids for the different fat types in a different manner.

Metabolizability of gross energy (AME_N/gross energy·100) of the diets was significantly influenced by fat type whereas no other tested effects proved to be significant (Table 4). The concentration of AME_N was additionaly clearly affected by fat inclusion level in a linear related manner (Table 4). All tested effects for metabolizability of gross energy and AME_N-contents of the pure fats as calculated by the difference were significant. It should be noted that in some cases the so-calculated AME_N-contents far exceed their gross energy contents.

Measured AME_N-content, utilization of crude fat and fatty acids as well as the corresponding amounts of crude fat and fatty acids excreted by the hens fed the low-fat diet is given in Table 5. The high standard deviations for all these parameters should be noted.

7.2 Regressions

Both the regression results (parameters and their significance) and derived parameters (AME_N, AME, apparent and true utilization of crude fat, total and particular fatty acids) are presented in Table 6. Goodness of fit as indicated by determination measure (r^2) was greater than 0.92 in all cases and greater than 0.98 for most regressions.

Table 5.
Effect of feeding a low-fat diet (0.32 %) on utilization and excretion of fat and fatty acids and on AME_N-concentration (n=10)

	Mean value	Standard deviation
AME_N (MJ/kg)	10.7	0.8
Utilization (%)		
Crude fat	-98.7	95.1
Palmitic acid (C16:0)	-82.8	88.6
Stearic acid (C18:0)	-57.0	97.1
Oleic acid (C18:1)	8.6	47.7
Linoleic acid (C18:2 n-6)	15.1	44.7
Linolenic acid (C18:3 n-3)	51.7	26.5
Excretion (mg per day per $kg^{0.75}$ of live weight)		
Crude fat	376	158
Palmitic acid (C16:0)	32	14
Stearic acid (C18:0)	9	5
Oleic acid (C18:1)	41	19
Linoleic acid (C18:2 n-6)	69	36
Linolenic acid (C18:3 n-3)	6	3
Σ of main fatty acids	157	

Generally, the lower the error probability for a given parameter estimation is, the more it contributes to minimizing the loss function of the regression approach, the lower its standard error will be. This also means that insignificant parameter estimates should be viewed with caution since they can vary without changing the determination value too much.

8 Discussion

The regressively estimated AME_N-content of palm oil was 38 to 47 % lower than that of the other fat types. These marked differences are caused by the differences in apparent and true fat utilization which in turn might be explained by differences in fatty acid utilization. The poor utilization of palm oil was probably caused by an obviously high free fatty acid content. It was shown by Wiseman and Salvador (1991) and by Wiseman et al. (1991) that free fatty acid content might markedly influence AME_N-contents of fats. For example, AME-content of successive blends of palm oil with palm acid oil decreased from 32.2 $MJ \cdot kg^{-1}$ to 27.5 $MJ \cdot kg^{-1}$ in cocks and from 27.7 $MJ \cdot kg^{-1}$ to 14.8 $MJ \cdot kg^{-1}$ in 1.5 weeks old chicks when the free fatty acid content of this palm oil-palm acid oil blend was increased from approximately 60 $g \cdot kg^{-1}$ to 920 $g \cdot kg^{-1}$, respectively. Therefore, the free fatty acid content of the palm oil batch used in the experiment was probably very high. All other tested fats were just refined or untreated fats. Therefore, it seems reasonable to assume that their free fatty acid content was less than 50 $g \cdot kg^{-1}$. At this level, no adverse effects on fat utilization need to be considered.

This negative effect of high contents of free fatty acids in palm oil on AME is caused by a poor crude fat and fatty acid utilization. Apparent crude fat utilization was only 55.4 % for palm oil whereas 70.7 % (Table 6) were determined for beef tallow although both fat types contained comparable contents of the sum of saturated and unsaturated fatty acids (55 % vs. 63 % and 45.3 % vs. 36.7 %, respectively). The detrimental effect of increasing amounts of free fatty acids in the diet was also supported by the fact that crude fat utilization and utilization of palmitic acid, stearic acid and oleic acid decreased at the same time (Table 3) whereas all these utilization figures from the other fats increased with fat dosage or appeared unaffected. Another mechanism of fatty acid utilization than the negative effect of free fatty acids might explain the differences in fat and fatty acid utilization and consequently in AME_N-contents between beef tallow and coconut oil. The apparent fat utilization is approximately 17 % higher in coconut oil, although this fat type contains 7 % more saturated fatty acids than beef tallow (70 % vs. 63 %). This is mainly due to the high proportions of the highly digestible lauric acid in coconut oil when compared to the poor digestibility of palmitic and stearic acid as the main saturated fatty acids in beef tallow. It has been reviewed by Dänicke (2000) that in saturated fatty acids, the polarity and micellar solubility increases as the chain length decreases, which becomes obvious in the differences in fatty acid utilization. Based on an evaluation of the literature Dänicke (2000) found the increases in absorbability of fatty acids in the following order: C18:0<C16:0<C14:0<C18:1, C18:2, C18:3. This general order was essentially confirmed by the present study. Additionally, absorbability of lauric acid might be placed at about that of myristic acid in the above mentioned order. Differences in utilization of a particular fatty acid but originating from different fat types have to be discussed in the context of total fatty acid composition of that fat. For example, small amounts of unsaturated fatty acids combined with long chain saturated fatty acids will improve the utilization of the latter considerably since their micellar solubility is facilitated. This effect, which is also known as "fatty acid synergism" (e.g. Leeson and Summers, 1976; Wiseman and Lessire, 1987), can be evaluated when the measured fatty acid utilization of a fat blend exceeds the mean weighed utilization calculated from the utilization of that fatty acid determined with each fat individually. Such synergistic effects were also detected in the present study. Measured utilization of palmitic and stearic acid of the beef tallow - soybean oil blend was 6 % and 9 % higher than the expected utilization. However, this synergism decreased to 3 % for the total crude fat and disappeared when the AME_N-contents were considered.

Total fatty acid utilization clearly reflected similar relationships between fats as observed for crude fat utilization. Correlation between both utilization measures was 0.99. The consistently lower utilization values for crude fat suggest that fat-soluble compounds other than fatty acids were less utilizable in the total crude fat fraction.

A further aim of this study was to estimate true utilization of fat and fatty acids by regressing the intake on the excretion. This type of regression yields an intercept on ordinate which can be interpreted as endogenous or metabolic fat loss. In order to standardize this parameter both intake and excretion were related to metabolic body weight. It can be taken from Table 6 that true utilization of fat and fatty acids were only slightly higher than the respective apparent values which would suggest a relatively low contribution of endogenous fat losses. Indeed, from the intercept on ordinate it can be deduced that endogenous fat losses amounted to only 136 $mg \cdot d^{-1} \cdot W^{-0.75}$. Although balance data of all observations (n=130) contributed to this value in a regressive manner (Figure 1), the so-derived endogenous fat losses should be treated carefully since they can only be taken as a trend (p=0.068). From the standard error of this parameter (69 $mg \cdot d^{-1} \cdot W^{-0.75}$) a 95 %-confidence interval from 6 to 278 $mg \cdot d^{-1} \cdot W^{-0.75}$ can be constructed. Mean endogenous fat losses can be expected within this range (p=0.95). From a comparison of the regressively derived endogenous fat losses with the measured crude fat excretion of hens fed the

Table 6.
Summary of multiple linear regression analysis for estimation of AME_N-concentrations and apparent and true utilization of fat and fatty acids of various fat types

y	*x*	*a* (Intercept on ordinate)	Regression slopes *b1* (Palm oil)	*b2* (Coco-nut oil)	*b3* (Peanut oil)	*b4* (Olive oil)	*b5* (Beef tallow)	*b6* (Soy-bean oil)	*b7* (Saf-flower oil)	*b8* (Beef tallow-soybean oil blend)	Residual standard deviation	r^2
AME_N (MJ/kg)	*g CF per kg diet*	*10.8*	*0.009*	*0.021*	*0.027*	*0.025*	*0.018*	*0.025*	*0.027*	*0.021*	*0.81*	*0.968*
p[1]		*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*		
AME_N of fats (MJ/kg; solution when x=1000g)			**20.0**	**32.1**	**38.1**	**36.3**	**28.3**	**35.6**	**38.0**	**32.2**		
g ap. util. CF per kg diet	*g CF per kg diet*	*-1.570*	*0.555*	*0.877*	*0.928*	*0.943*	*0.709*	*0.940*	*0.958*	*0.850*	*6.93*	*0.997*
p[1]		*0.280*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*		
Ap. CF-utilization (%; solution when x=1000g)			**55.4**	**87.5**	**92.7**	**94.2**	**70.7**	**93.8**	**95.7**	**84.8**		
CF-excretion ($mg \cdot d^{-1} \cdot W^{-0.75}$)	*CF-intake ($mg \cdot d^{-1} W^{-0.75}$)*	*0.136*	*0.434*	*0.119*	*0.067*	*0.053*	*0.292*	*0.057*	*0.037*	*0.145*	*0.36*	*0.987*
p[1]		*0.068*	*<0.001*	*<0.001*	*<0.001*	*0.002*	*<0.001*	*0.001*	*0.027*	*<0.001*		
True CF-utilization (%; (1-b)*100)			**56.6**	**88.1**	**93.3**	**94.7**	**70.8**	**94.3**	**96.3**	**85.5**		
g ap. util. FA per kg diet	*g FA per kg diet*	*0.307*	*0.670*	*0.893*	*0.960*	*0.966*	*0.757*	*0.956*	*0.975*	*0.877*	*5.21*	*0.998*
p[1]		*0.776*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*		
Ap. FA-utilization (%; solution when x=1000g)			**67.0**	**89.3**	**96.0**	**96.7**	**75.7**	**95.6**	**97.5**	**87.8**		
FA-excretion ($mg \cdot d^{-1} W^{-0.75}$)	*FA-intake ($mg \cdot d^{-1} \cdot W^{-0.75}$)*	*-0.011*	*0.324*	*0.106*	*0.039*	*0.033*	*0.241*	*0.044*	*0.023*	*0.121*	*0.28*	*0.986*
p[1]		*0.846*	*<0.001*	*<0.001*	*0.004*	*0.016*	*<0.001*	*0.003*	*0.059*	*<0.001*		
True FA-utilization (%; (1-b)*100)			**67.6**	**89.4**	**96.1**	**96.7**	**75.9**	**95.6**	**97.7**	**87.9**		
g ap. util. C18:0 per kg diet	*g C18:0 per kg diet*	*-0.135*	*0.729*	*0.744*	*0.955*	*1.002*	*0.549*	*0.885*	*0.980*	*0.646*	*0.94*	*0.995*
p[1]		*0.486*	*<0.001*	*<0.001*	*<0.001*	*0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*		
Ap. C18:0-utilization (%; solution when x=1000g)			**72.9**	**74.4**	**95.5**	**100.1**	**54.9**	**88.5**	**98.0**	**64.6**		
C18:0-excretion ($mg \cdot d^{-1} \cdot W^{-0.75}$)	*C18:0-intake ($mg \cdot d^{-1} W^{-0.75}$)*	*0.011*	*0.262*	*0.252*	*0.039*	*-0.010*	*0.446*	*0.101*	*0.015*	*0.347*	*0.06*	*0.994*
p[1]		*0.340*	*<0.001*	*<0.001*	*0.370*	*0.963*	*<0.001*	*0.186*	*0.761*	*<0.001*		
True C18:0-utilization (%; (1-b)*100)			**73.8**	**74.8**	**96.1**	**101.0**	**55.4**	**89.9**	**98.5**	**65.3**		
g ap. util. C16:0 per kg diet	*g C16:0 per kg diet*	*0.337*	*0.577*	*0.758*	*0.909*		*0.701*	*0.892*	*0.915*	*0.794*	*2.58*	*0.992*
p[1]		*0.585*	*<0.001*	*<0.001*	*<0.001*		*<0.001*	*<0.001*	*<0.001*	*<0.001*		
Ap. C16:0-utilization (%; solution when x=1000g)			**57.7**	**75.8**	**90.9**		**70.1**	**89.2**	**91.5**	**79.4**		
C16:0-excretion ($mg \cdot d^{-1} \cdot W^{-0.75}$)	*C16:0-intake ($mg \cdot d^{-1} \cdot W^{-0.75}$)*	*-0.011*	*0.415*	*0.230*	*0.081*		*0.293*	*0.100*	*0.068*	*0.199*	*0.14*	*0.988*
p[1]		*0.725*	*<0.001*	*0.002*	*0.152*		*<0.001*	*0.153*	*0.371*	*<0.001*		

True C16:0-utilization (%; (1-b)*100)			**58.5**	**77.0**	**91.9**		**70.7**	**90.0**	**93.2**	**80.1**		
g ap. util. C18:1 per kg diet	*g C18:1 per kg diet*	*0.363*	*0.760*	*0.913*	*0.971*	*0.973*	*0.924*	*0.955*	*0.925*	*0.927*	*2.10*	*0.999*
p[1]		*0.409*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*		
Ap. C18:1-utilization (%; solution when x=1000g)			**76.0**	**91.4**	**97.2**	**97.4**	**92.4**	**95.6**	**92.5**	**92.7**		
C18:1-excretion (mg·d^{-1}*·W*$^{-0.75}$*)*	*C18:1-intake (mg·d*$^{-1}$*·W*$^{-0.75}$*)*	*-0.015*	*0.234*	*0.077*	*0.026*	*0.026*	*0.073*	*0.043*	*0.063*	*0.069*	*0.12*	*0.960*
p[1]		*0.513*	*<0.001*	*0.096*	*0.006*	*<0.001*	*0.001*	*0.040*	*0.225*	*0.002*		
True C18:1-utilization (%; (1-b)*100)			**76.6**	**92.3**	**97.4**	**97.4**	**92.7**	**95.7**	**93.7**	**93.1**		
g ap. util. C18:2 per kg diet	*g C18:2 per kg diet*	*-0.282*	*0.733*	*0.843*	*0.960*	*0.920*	*0.885*	*0.971*	*0.988*	*0.979*	*0.68*	*1.000*
p[1]		*0.345*	*0.014*	*0.848*	*<0.001*	*0.011*	*0.447*	*<0.001*	*<0.001*	*<0.001*		
Ap. C18:2-utilization (%; solution when x=1000g)			**73.3**	**84.3**	**96.0**	**91.9**	**88.5**	**97.1**	**98.8**	**97.8**		
C18:2-excretion (mg·d^{-1}*·W*$^{-0.75}$*)*	*C18:2-intake (mg·d*$^{-1}$*·W*$^{-0.75}$*)*	*0.020*	*0.259*	*0.129*	*0.038*	*0.077*	*0.086*	*0.028*	*0.011*	*0.018*	*0.04*	*0.924*
p[1]		*0.025*	*<0.001*	*0.058*	*<0.001*	*0.007*	*0.322*	*<0.001*	*<0.001*	*0.022*		
True C18:2-utilization (%; (1-b)*100)			**74.1**	**87.1**	**96.2**	**92.3**	**91.4**	**97.2**	**98.9**	**98.2**		
g ap. util. C18:3 per kg diet	*g C18:3 per kg diet*	*-0.123*				*1.006*		*1.003*		*1.018*	*0.04*	*1.000*
p[1]		*0.003*				*<0.001*		*<0.001*		*<0.001*		
Ap. C18:3-utilization (%; solution when x=1000g)						**100.6**		**100.3**		**101.8**		
C18:3-excretion (mg·d^{-1}*·W*$^{-0.75}$*)*	*C18:3-intake (mg·d*$^{-1}$*·W*$^{-0.75}$*)*	*0.001*				*0.011*		*0.015*		*0.008*	*<0.01*	*0.926*
p[1]		*0.007*				*0.002*		*<0.001*		*0.013*		
True C18:3-utilization (%; (1-b)*100)						**98.9**		**98.5**		**99.2**		
g ap. util. C12:0 per kg diet	*g C12:0 per kg diet*	*0.576*		*0.939*							*<0.01*	*1.000*
p[1]		*0.004*		*<0.001*								
Ap. C12:0-utilization (%; solution when x=1000g)				**93.9**								
C12:0-excretion (mg·d^{-1}*·W*$^{-0.75}$*)*	*C12:0-intake (mg·d*$^{-1}$*·W*$^{-0.75}$*)*	*-0.011*		*0.053*							*0.01*	*0.982*
p[1]		*0.467*		*0.009*								
True C12:0-utilization (%; (1-b)*100)				**94.7**								
g ap. util. C14:0 per kg diet	*g C14:0 per kg diet*	*0.119*		*0.867*			*0.922*			*0.924*	*0.27*	*1.000*
p[1]		*0.482*		*<0.001*			*<0.001*			*<0.001*		
Ap. C14:0-utilization (%; solution when x=1000g)				**86.7**			**92.2**			**92.4**		
C14:0-excretion (mg·d^{-1}*·W*$^{-0.75}$*)*	*C14:0-intake (mg·d*$^{-1}$*·W*$^{-0.75}$*)*	*-0.006*		*0.134*			*0.078*			*0.070*	*0.01*	*0.990*
p[1]		*0.324*		*<0.001*			*0.014*			*0.173*		
True C14:0-utilization (%; (1-b)*100)				**86.6**			**92.2**			**93.0**		

[1]Probability of parameter estimation

Abbreviations: ap., apparent; util., utilized; CF, crude fat; FA, sum of main fatty acids; W, live weight (kg); C12:0, lauric acid; C14:0, myristic acid; C16:0, palmitic acid; C18:0, stearic acid; C18:1, oleic acid; C18:2 n-6, linoleic acid; C18:3 n-3, linolenic acid

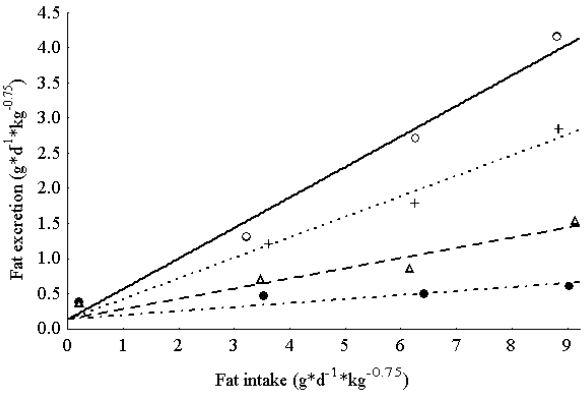

Figure 1.
Fat excretion of laying hens fed semi-purified diets differing in fat type and fat concentration in dependence on fat intake
(Palm oil , beef tallow ,
beef tallow : soybean oil = 50:50 , soybean oil)

basal diet (Figure 1, Table 5) it becomes clear that the latter far exceed the regressive value. This measured crude fat excretion must approximate the endogenous fat losses if it is assumed that from the low fat intake (approximately 200 mg·d^{-1}·W$^{-0.75}$) only 20 mg·d^{-1}·W$^{-0.75}$ (90 % absorption assumed) were excreted together with the endogenous fat losses. This dietary originated fat excretion would be approximately 5 % of total crude fat excretion (376 mg·d^{-1}·W$^{-0.75}$). However, as with the regressively estimated endogenous fat losses, a relatively high standard deviation has to be taken into account (Table 5). Veen et al. (1974) reported endogenous fat losses for broilers of 4.87 g·kg^{-1} diet which was derived from fat excretion values of broilers fed a corn-soybean meal basal diet (3.2 % crude fat) corrected for an assumed basal diet fat excretion. Endogenous fat losses as observed in the present study would amount to 5.5 g·kg^{-1} diet and 2.1 g·kg^{-1} diet (measured and estimated, respectively) which would include the above-mentioned value from the literature. Because of the uncertainties in determination of endogenous fat losses according to both methods it seems reasonable to expect endogenous fat losses of between 2.1 and 5.5 g·kg^{-1} diet.

Estimation of endogenous fatty acid losses by regression followed the trend of an underestimation as described for crude fat excretion. Only the endogenous excretion of linoleic acid and of linolenic acid were significant. Therefore, these so-derived values will not be discussed further. The sum of the main fatty acids excreted by the hens fed the low fat diet (Table 5) agreed with the value of 2.11 g·kg^{-1} diet reported by Veen et al. (1974) when expressed on the diet basis (2.1 g·kg^{-1}).

The relatively wide range in regressive derived fat-AME_N-contents (20.0 MJ·kg^{-1} ... 38.1 MJ·kg^{-1}) and apparent fat utilization (55.4 % ... 95.7 %) allowed further regressive evaluation of the data. When the linear regression of "g utilized crude fat per kg fat" on AME_N-content of fats was forced through the origin then it was found that per g apparent utilized crude fat approximately 38.7 kJ AME_N were available (r^2=0.95). This value reaches nearly the gross energy value of the most fats and is close to the value of 39.8 kJ per g utilized fat as estimated by Hoffmann (1994) from multiple regression of utilized nutrients from total diets on AME-contents. Therefore, at least 95 % of absorbed crude fat energy is metabolically available.

Based on the assumption that crude fat utilization of pure fats can also be interpreted as metabolizability of fat energy some further calculations can be made.

Firstly, if the regressively derived apparent crude fat utilization is multiplied by the gross energy of the respective fats a measure for AME can be derived (Table 7). Because this AME-value is not N-corrected, the uncorrected, but by regression estimated AME-values of the particular fats are also shown in Table 8 for comparison. The maximum absolute difference between both estimates was 11 % in case of palm oil.

Table 7.
Comparison of ME-concentrations of various fat types as calculated by the "gross energy-fat utilization-method"

	Gross energy[1] (MJ/kg)	Apparent fat utilization (~AME/GE -ratio of fat)	AME (MJ/kg) (= gross energy[1] · apparent fat utilization/100)	True fat utilization (~TME/GE-ratio of fat)	TME (MJ/kg) (= gross energy[1]·true fat utilization/100)	TME_N (=0.986·TME)
Palm oil	39.3	55.4	21.8	56.6	22.2	21.9
Coconut oil	37.6	87.5	32.9	88.1	33.1	32.6
Peanut oil	39.4	92.7	36.5	93.3	36.8	36.3
Olive oil	39.3	94.2	37.0	94.7	37.2	36.7
Beef tallow (T)	39.5	70.7	27.9	70.8	28.0	27.6
Soybean oil (S)	39.3	93.8	36.9	94.3	37.1	36.6
Safflower oil	39.3	95.7	37.6	96.3	37.8	37.3
S:T = 50:50	39.4	84.8	33.4	85.5	33.7	33.2

[1] Values from Prabucki 1977

Table 8.
Comparison of ME-concentrations of different fat types as calculated by the regression method

	Gross energy[1] (MJ/kg)	AME (MJ/kg)	AME/GE[1] (%)	AME_N (MJ/kg)	AME_N/GE[1] (%)
Palm oil	39.3	19.7	50.1	20.0	50.9
Coconut oil	37.6	32.2	85.6	32.1	85.3
Peanut oil	39.4	39.5	100.3	38.1	96.6
Olive oil	39.3	36.8	93.6	36.3	92.2
Beef tallow (T)	39.5	28.3	71.6	28.3	71.8
Soybean oil (S)	39.3	35.5	90.3	35.6	90.6
Safflower oil	39.3	38.9	99.0	38.0	96.7
S:T = 50:50	39.4	32.9	83.5	32.2	81.7

[1] Values from Prabucki 1977

Secondly, the regressively derived AME_N-contents of the fats were divided by their gross energy content to yield an estimate for metabolizability of fat energy or apparent fat utilization. Again, whereas the difference between the so-estimated apparent fat utilization and the regressively evaluated apparent fat utilization amounted 8 % for palm oil, the differences for all other tested fats were lower than 4 %.

Thirdly, if the gross energy of the fats is multiplied by the true fat utilization, which might also be interpreted as true metabolizability of fat, an estimate for true ME (TME)-values can be obtained (Table 7). Clearly, since all true fat utilization values were higher or comparable with their apparent counterparts, the TME-values are accordingly higher than the similarly derived AME-values.

Fourthly, in order to correct the TME-values for a zero N-retention, the slope derived from the regression of AME on AME_N (AME_N=0.986 · AME, r^2=0.993) was used as a correction factor. The so-corrected TME_N-contents of the different fat types are also shown in Table 7. TME_N-contents were only slightly higher than their corresponding AME_N-contents with the exception of peanut oil, beef tallow and safflower oil. However, the regression of AME_N on TME_N yielded a slope of one (TME_N = 1·AME_N, r^2=0.95); therefore it seems that there is no need to correct AME_N-contents of these tested fats for endogenous metabolic energy losses.

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