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DIGESTIVE AND METABOLIC UTILIZATION OF LAURIC, MYRISTIC AND STEARIC ACID IN COWS, AND ASSOCIATED EFFECTS ON MILK FAT QUALITY

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In an experiment with 3 × 6 Brown Swiss cows, the effects of dietary supplementations (40 g/kg) of non-esterified lauric (12:0), myristic (14:0) and stearic acid (18:0) on digestibility, metabolisability, milk fat composition and melting properties were investigated. The diet consisted of forage and concentrate in a ratio of 3:2. Cows were fed the C18:0 supplemented diet for 10 days before treatment feeding started for a 15-day experimental period where, at the end, excreta were quantitatively collected and gaseous exchange was measured. The DM intake averaged 17.9 kg/d for the C14:0 and C18:0 diets and was reduced ($P < 0.05$) by 18% in the C12:0 diet. The realised intakes of total C12:0, C14:0 and C18:0 amounted to 368, 391 and 617 g/d in the respective groups. The efficiency of ME utilization for lactation was higher ($P < 0.001$) in the C12:0 group than in the two other groups indicating differences in metabolism of C12:0 in comparison with C14:0 and C18:0. Shifts in dietary fatty acid supplementation were clearly reflected in the milk fat composition. Associated changes were elevated CLA and C18:1 *trans* when supplementing C12:0, and a high C18:1 to C16:0 ratio ($P < 0.05$) in the C12:0 and C18:0 groups which resulted in an easier melting milk fat than with supplementary C14:0. Despite certain favourable effects of C12:0 in metabolic energy utilization and milk fat melting properties (relative to C14:0), more research is needed on how to improve its palatability for dairy cows.

Keywords: Energy; Fatty acids; Intake; Dairy cow; Ruminants

1. INTRODUCTION

In higher yielding dairy cows, especially during early lactation, diet supplementation with fats is recommended as an efficient means to reduce the metabolic energy deficit (Palmquist and Jenkins, 1980; Chilliard, 1993). It is often suggested (*e.g.*, by Bergner and Sommer, 1994) to use only rumen-protected fats and fatty acids (FA) for this purpose, since unprotected FA would impair the ruminal fermentation of structural

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carbohydrates with the consequence of a reduced nutrient availability from the non-fat components of the diet. However, protected or not protected, saturated FA are known to be less adverse in that respect than unsaturated FA (Jilg *et al.*, 1988). In line with that, about 25 g/kg dietary DM of unprotected coconut oil, a fat rich in the saturated medium-chain FA (MCFA) lauric acid (C12:0) and myristic acid (C14:0), had no adverse effects on fibre digestion and body energy retention of lambs when provided isoenergetically to the same amount of rumen-protected fat (Machmüller *et al.*, 2000). Even dietary coconut oil proportions as high as 70 g/kg had only insignificant effects on fibre digestion and heat production of adult sheep (Machmüller and Kreuzer, 1999). As these studies showed, coconut oil reduced methanogenesis in ruminants, and C12:0 and C14:0 have been identified *in vitro* as the FA responsible for this favourable effect (Dohme *et al.*, 2001) although they differ in their mode of action (Soliva *et al.*, 2003). The MCFA are also known to be predominantly used for energetic purpose in metabolism of rodents (Lavau and Hashim, 1978). This might explain why sometimes (Rohr *et al.*, 1978) there was no response to coconut oil in C12:0 and C14:0 proportion of milk fat, while others (Rindsig and Schultz, 1974; Christie, 1979; Storry, 1981) reported significant changes. Given these controversial findings, it remains still unclear to which extent MCFA are digested and metabolically utilized for energetic purposes or for the formation of milk fat. The latter could be particularly crucial for the implementation of feeding strategies based on these fats or FA, since dietary MCFA are suspected to enhance plasma total and low density lipoprotein (LDL) cholesterol concentrations in man, with the consequence of an increased risk of coronary heart diseases (CHD) in man (Williams, 2000). However, there is gradual shift in the assessment of MCFA for human nutrition. De Roos *et al.* (2001) recommended the use of tropical fats with high MCFA contents to replace the often used partially hydrogenated soybean oil. This oil is rich in *trans*-FA which are considered as to be more hazardous in terms of promoting CHD. Moreover, certain protective properties of MCFA against zoonoses were described (Wang *et al.*, 1993). Also food manufacturers demand solid fats in order to achieve the desired texture and firmness of many products. It is also unclear if and to which extent the use of MCFA affects the excretion of other FA with milk, particularly those which are also of presumed health impact (*trans*-FA and conjugated linoleic acids).

The aim of the present study was to investigate in dairy cows the effects of supplements of C12:0 and C14:0 in comparison with the long-chain saturated FA, stearic acid (C18:0), which is considered inert in rumen fermentation and neutral in terms of health aspects in human nutrition. The study should clarify the extent to which these FA are digested, metabolically used and excreted with milk, and their efficacy to modify milk fat composition and its melting properties.

2. MATERIAL AND METHODS

2.1. Experimental design and feeding

The experiment was based on a mono-factorial design and was carried out with eighteen early-lactating multiparous Brown Swiss cows. Initial average performance data (mean $\pm$ SD) were 627 $\pm$ 54 kg BW and 31.0 $\pm$ 4.6 kg milk yield/d with 41.1 $\pm$ 4.9 g fat/kg, 31.2 $\pm$ 1.4 g protein/kg, and 51.2 $\pm$ 1.7 g lactose/kg. The animals were allocated to three dietary treatments (n = 6). Measurements were performed in two subsequent

series with three cows per treatment. The treatment diets differed only in the type of FA, namely lauric acid (C12 : 0), myristic acid (C14 : 0) and stearic acid (C18 : 0), supplemented at a level of 40 g/kg feed DM (Table I). For better attribution of the effects, non-esterified FA were employed which still allows extrapolation of effects to MCFA-rich fats since differences in effects of non-esterified and esterified FA are quite low (Bergner and Sommer, 1994). All FA products (Edenor C12, C14 and C18; Cognis Deutschland GmbH, Düsseldorf, Germany) had a purity of ≥ 98%. The complete diets were composed of forage and a barley-based concentrate in a ratio of 3 : 2. The forage consisted of a mixture of grass silage (dominated by young ryegrass), maize silage and hay (late cut from permanent meadows highly diverse in species composition). Unintentionally, the C14 : 0 concentrate was supplemented with too low amounts of this

TABLE I Composition of the diets

Fatty acid treatment	*C12 : 0*	*C14 : 0*	*C18 : 0*
Ingredients [g/kg DM]			
Forage			
Grass silage	306	306	306
Maize silage	192	192	192
Hay	102	102	102
Concentrates			
Barley	264	264	264
Maize gluten	56	56	56
Molasses	28	28	28
Mineral and vitamin premix[1]	12	12	12
Lauric acid (C12 : 0)	40	–	–
Myristic acid (C14 : 0)	–	40	–
Stearic acid (C18 : 0)	–	–	40
Analysed composition [per kg DM]			
OM [g]	920	918	919
Total fatty acids [g]	63	44	56
CF [g]	163	164	164
NDF [g]	329	318	320
Non-NDF carbohydrates [g]	371	398	386
Crude protein [g]	156	159	158
Absorbable protein at the duodenum [g][2]	100	102	101
NE_l [MJ][2]	7.3	7.0	7.2
Fatty acid composition [% of total fatty acid methyl esters]			
C12 : 0	63.98	0.76	1.00
C14 : 0	0.84	49.00	0.14
C16 : 0	6.05	8.63	6.30
C18 : 0	1.22	2.21	63.92
C14 : 1	0.45	0.65	0.51
C16 : 1	0.69	0.99	0.78
C18 : 1	4.68	6.73	4.91
C18 : 2	13.74	19.18	13.15
C18 : 3	7.62	10.81	8.46
Total C18	27.25	38.93	90.45
Total saturated fatty acids	72.09	60.60	71.35
Total monoenoic fatty acids	5.82	8.36	6.21
Total polyenoic fatty acids	21.35	29.99	21.61

[1]Supplied per kg DM concentrate: 5.1 g Ca, 1.5 g P, 1.2 g Mg, 1.2 g Na, 30,000 IU vitamin A, 6,000 IU vitamin D_3, 45 mg vitamin E.
[2]According to RAP (1999).

FA as is also obvious from the content analysed; however, C14:0 was still the predominant FA in this diet (Table I). The complete diets offered were similar in contents of fibre, protein and calculated NE_l. Feed was allocated in a restricted regime based on the individual requirements of the cows for maintenance and milk yield as defined by RAP (1999). Forage was mixed daily and given twice a day. The allocated amount of concentrate was manually fed in five portions a day. The cows were tethered in individual stalls complete with slatted floor equipped for balance trials. Conditions were similar in the respiration chambers. The cows were milked twice a day, and a Metatrom® system (Westfalia Landtechnik, Oelde, Germany) was used to record milk yield and to automatically collect milk samples.

2.2. Experimental techniques

Each animal passed a 10-day adjustment period on the C18:0 diet and a 15-day experimental period receiving either the C12:0, C14:0 or C18:0 diet. During a collection period, comprising the last six days of the experimental period, faeces and urine were quantitatively collected with additional measurements of gaseous exchange (oxygen consumption and excretion of carbon dioxide and methane) on the third and fourth day of the collection period. The two open circuit respiration chambers as described by Sutter and Beever (2000) were air conditioned (measured microclimate: temperature 17.3 ± 0.4°C (mean $\pm$ SD); relative humidity 59.3 ± 1.1%; air flow 27.2 ± 0.7 m^3/h). Composition of incoming and outgoing air (internal chamber volume: 20 m^3) was measured using infrared analysers (Binos; Lebold-Heraeus, Zurich, Switzerland) for carbon dioxide and methane and by a paramagnetic analyser (Oxymat 6; Siemens AG, Karlsruhe, Germany) for oxygen. The volume of the air removed from the chambers was recorded continuously using in-line electronic flow meters (Swingwirl DV 630; Flowtec AG, Reinach, Switzerland). The chamber system was manually calibrated in advance of the respiratory measurements, and automatic calibrations were performed every 3 h including one calibration at the end of the 48 h period. Prior to the start of the experimental period, the animals got accustomed to the conditions of the respiration chambers by putting them into the chambers for 1 day.

During the collection period, forage intake was automatically recorded by a computerized feeding system (Westfalia Landtechnik, Oelde, Germany). Concentrate refusals were separately collected and weighed each day. Feed samples were obtained every day and pooled at the end of each collection period. Samples and refusals of forage were dried in an oven at 60° for 48 h. Homogenized daily faeces samples were stored at 4°C. Urine was collected in plastic canisters by the use of urinals which were attached around the vulva of the cow with Velcro® tapes fixed to the sheared skin by instant glue (Cyanolit, 3M AG Rüschlikon, Switzerland). Urine was gathered both without and, in a smaller subsample, with 5 M sulphuric acid, the latter to prevent gaseous N loss. Non-acidified urine was frozen at -20°C, acidified urine was first stored at 4°C. At the end of each collection period, the daily samples of faeces and urine of every cow were pooled and stored at -20°C. One part of faeces was dried at 60°C for 48 h. Faeces and dried feed samples were ground through a 0.75 mm screen.

The cows were weighed at the start of the control period as well as at the start and the end of the experimental period. During the collection period two milk samples of each cow were taken from every milking. One sample was immediately frozen and pooled to

one sample at the end of the collection period for nitrogen (N) determination and total FA content as well as FA profile. The other sample was conserved with Bronopol (BSM2, D&F Control, San Ramon, CA, USA) for the analysis of lactose and urea by infrared technique (Milkoscan 4000, Foss Electric, Hillerød, Denmark). The experiment was conducted in accordance with the Swiss guidelines for animal welfare and approved by the respective authority.

2.3. Laboratory analysis

Feeds, refusals and faeces were analysed by standard methods for contents of DM and OM (TGA-500, Leco Corporation, St. Joseph, MI, USA), CF (Naumann and Bassler, 1997) and NDF (Van Soest *et al.*, 1991; with the use of heat stable α-amylase). The determination of nitrogen (N) content of feed, refusals, fresh faeces, acidified urine and milk was carried out with an automatic C/N analyser (Leco-Analyser Type FP-2000, Leco Corporation, St. Joseph, MI, USA). With the same analyser the carbon content of non-acidified urine was measured. The GE contents of feeds, refusals, faeces and lyophilised milk were assessed by anisothermic bomb calorimetry (C 700 T, IKA-Werke, Staufen, Germany).

Fatty acids were extracted from feeds and faeces with hexane/isopropanol 3:2 (v/v), containing 100 mg/l butyl hydroxytoluol, using accelerated solvent extraction (ASE 200, Dionex Corporation, Sunnyvale, CA, USA) at 105°C and 10.34 MPa in three cycles with 100% flush volume. The preparation of the FA methyl esters (FAME) by transesterification as well as their analysis by gas chromatography were carried out as described in detail by Wettstein *et al.* (2001). The total FA content of feed and faeces was determined along with the analysis of the composition of individual FA. For this purpose commercially available coconut oil and canola oil were used as reference fats to determine an overall response factor relative to the internal standard (C11). The FA composition of the milk samples was analysed after cold transesterification (Suter *et al.*, 1997) with two different GC methods. A detailed description of the analysis and the interpretation of the chromatograms is given by Wettstein *et al.* (2001). Response factors for individual FAME used to calculate the FA proportions were determined with the standard fat BCR 164 (Institute for Reference Materials and Measurements, Geel, Belgium). The response factor for the quantification of total FA content was determined using dehydrated clarified butter.

The melting properties of milk fat were analysed by differential scanning calorimetry (DSC 2010, TA Instruments, Alzenau, Germany). Fat was obtained by centrifugation of the milk (sigma 204, Sigma Laborzentrifugen GmbH, Osterode am Harz, Germany) at 2400 *g* for 5 min. The supernatant was taken up in 10 ml aceton and passed through a filter paper (597 HY $^1/_2$, Schleicher & Schuell, Dassel, Germany). Subsequently, the samples were dried by evaporation, and 9 to 14 mg fat of each sample were weighed in aluminium pans, sealed and heated in the DSC to 80°C for 10 min to eliminate any crystal nuclei. The fat was then crystallized by cooling to − 60°C at a rate of 0.8°C/min under N_2 (40 ml/min) and held at this temperature for 10 min. The melting curves were recorded while heating from − 60°C to + 80°C at a rate of 5°C/min. Onset and offset temperatures as well as melting enthalpies were derived from the resulting profiles. The solid fat content at a given temperature was calculated from the respective areas of the melting curves.

2.4. Calculations and statistical analysis

The CP content of feed and faeces was calculated as 6.25 × N content and of milk as 6.38 × N. The non-NDF carbohydrates in feed and faeces were defined as the OM not incorporated in CP, total FA and NDF. Urine energy was computed from the contents of carbon and N in urine using the formula of Hoffmann and Klein (1980). For the calculations of methane energy and heat energy (energy expenditure), the standard equations of Brouwer (1965) were applied. The formula used for heat energy was based on the mean daily rates of oxygen consumption, carbon dioxide and methane production as well as urinary N excretion. In additional calculations, carbon dioxide release was corrected for the amount derived from the rumen fermentation process as outlined by Chwalibog *et al.* (1996). The efficiencies of ME utilization for maintenance (k_m) and lactation (k_l) were calculated as recommended by AFRC (1993) and executed by Sutter and Beever (2000). Data were subjected to the linear model (GLM) procedure of the SAS program (version 6.12, SAS Institute Inc., Cary, NC, USA). The type of supplemented FA was treated as effect for analysis of variance, applying average values from the 6 days of the collection periods. Multiple comparisons among means were carried out by the Tukey method.

3. RESULTS

3.1. Performance, nutrient digestibility and nitrogen balance

Feed intake, but not forage consumption, differed between treatment groups (Table II). Cows of the C12 : 0 group consumed significantly less concentrate than cows of all other groups. High refusals of the C12 : 0 concentrate were found in every single cow, and the amount of refusal either remained constant or only slightly decreased with time throughout the treatment feeding period. As a consequence, the ratio of forage-to-concentrate was higher in this group compared to the others (5 : 2 vs. 3 : 2). The BW of the cows remained unaffected by the treatments and was not different from the initial values before starting with the treatment feeding. The treatments did not significantly affect milk yield, contents of fat (total FA), protein and urea in milk while the lactose content was reduced with C12 : 0 and C14 : 0 supplementation. No significant treatment effects were observed in the apparent digestibilities of OM, CF, NDF and non-NDF carbohydrates.

As a consequence of the reduced DM consumption, in the C12 : 0 group also N-intake and daily N-excretion with faeces was reduced relative to the other two groups. Faecal N-loss relative to N-intake was highest with the C18 : 0 treatment followed by the C12 : 0 and the C14 : 0 groups. Milk-N excretion was similar for all diets; however, its proportion of total N-intake was higher with the C12 : 0 diet. Urinary-N loss did not differ among groups as well as its proportion of total N-intake and of total excreta-N. Body N-retention was positive on average of all diets, particularly with C14 : 0 supplementation, as in this group the proportionate N-excretion with faeces and milk was low.

3.2. Energy balance

The GE intake was lower in the C12 : 0 group compared to the other two groups (Table III). Differences were similar for digestible energy (DE) and ME, but no longer

TABLE II Performance, nutrient digestibilities and nitrogen turnover of cows fed different fatty acids

Fatty acid treatment	*C12:0*	*C14:0*	*C18:0*	*SEM*	P-*value*
Feed intake [kg/d]					
Total DM	14.7[b]	17.8[a]	17.9[a]	0.77	< 0.05
Forage DM	10.6	10.7	10.9	0.49	0.92
Concentrate DM	4.1[b]	7.1[a]	7.0[a]	0.38	< 0.001
Body weight [kg]	643	612	626	17.9	0.50
Milk yield and composition					
Milk yield [kg/d]	25.8	28.5	27.6	1.45	0.41
Total fatty acids [g/kg]	43.1	41.5	39.7	0.15	0.29
Protein [g/kg]	30.3	30.9	31.7	0.07	0.43
Urea [mg/dl]	27.1	24.5	25.9	0.19	0.64
Lactose [g/kg]	49.6[b]	49.7[b]	51.6[a]	0.04	< 0.01
Apparent digestibilities					
OM	0.708	0.729	0.703	0.0100	0.18
CF	0.558	0.610	0.628	0.0229	0.11
NDF	0.536	0.573	0.576	0.0225	0.40
Non-NDF carbohydrates	0.812	0.866	0.907	0.0464	0.37
N-balance [g/d]					
N-intake	354[b]	447[a]	449[a]	24.0	< 0.05
Faecal N-excretion	135[b]	162[ab]	182[a]	10.0	< 0.05
Urinary N-excretion	85	99	108	8.2	0.17
N-excretion with milk	122	138	137	5.6	0.13
Body N-retention	12[b]	50[a]	23[ab]	9.8	< 0.05
N balance					
Faecal-N [% of N-intake]	38.4[ab]	36.1[b]	40.5[a]	1.11	< 0.05
Urine-N [% of N-intake]	23.8	21.9	24.3	1.64	0.56
[% of faecal-N + urine-N]	38.2	37.8	37.1	1.66	0.90
Milk-N [% of N-intake]	34.8[a]	30.9[b]	30.5[b]	0.85	< 0.01

Mean values within the same line sharing no common superscript are significantly different ($P < 0.05$).

significantly different between the C12:0 and the C18:0 treatment. Energy loss via faeces, methane and heat was significantly lowest with the C12:0 diet compared to the C18:0 and C14:0 diets which were similar in level. When corrected for assumed carbon dioxide release from fermentation, heat production level was lower across treatments, but treatment differences remained. No differences among diets occurred in the energy excretion with urine and milk. Body energy retention was around zero with C14:0 and C18:0 (slightly negative without correction for fermentative carbon dioxide) and negative with C12:0 (not significantly different from the other groups due to high individual variation).

The apparent energy digestibility was higher with C14:0 than with C18:0, and the C12:0 group took an intermediate position. Although ranked similarly, differences in metabolizability of energy were not significantly different. Supplementation of each of the MCFA resulted in higher efficiencies of ME utilization for maintenance compared with the C18:0 treatment. For lactation purpose, the efficiency was highest with C12:0, and was almost equal for the C18:0 and the C14:0 diet; this both for uncorrected and corrected heat production values. The respiratory quotient, expressed as the ratio of carbon dioxide production to oxygen consumption, was lowest with C12:0.

TABLE III Energy turnover of cows fed different fatty acids

Fatty acid treatment	*C12:0*	*C14:0*	*C18:0*	*SEM*	P-*value*
Energy balance [MJ/d]					
Intake					
GE	269.5[b]	329.3[a]	338.5[a]	24.04	< 0.01
Digestible energy	184.4[b]	228.7[a]	218.6[ab]	10.74	< 0.05
ME	161.0[b]	200.4[a]	189.7[ab]	10.38	< 0.05
Excretion					
Faeces	85.0[b]	100.6[ab]	119.9[a]	5.40	< 0.001
Urine	6.7	8.0	7.6	0.35	0.05
Methane	16.8[b]	20.3[a]	21.3[a]	0.94	< 0.01
Heat[1]	98.7[b]	114.9[a]	113.2[a]	3.72	< 0.05
Heat (corrected)[2]	92.3[b]	107.1[a]	105.1[ab]	3.59	< 0.05
Retention					
Milk	81.6	88.0	85.2	4.46	0.60
Body	− 19.3	− 2.4	− 8.7	6.55	0.22
Body (corrected)[2]	− 12.9	5.3	− 0.6	6.57	0.17
Coefficients of utilization					
Utilization of GE					
Apparent digestibility	0.685[ab]	0.694[a]	0.645[b]	0.0116	< 0.05
Metabolizability	0.597	0.608	0.558	0.0136	0.51
Efficiency of ME utilization[3]					
Maintenance [k_m]	0.712	0.716	0.698	0.0048	0.05
Lactation [k_l]	0.694[a]	0.616[b]	0.628[b]	0.0104	< 0.001
Lactation [k_l, corrected][2]	0.734[a]	0.651[b]	0.669[b]	0.0114	< 0.001
Respiratory quotient (CO_2/O_2)	1.00	1.05	1.05	0.015	0.05

Mean values within the same line sharing no common superscript are significantly different ($P < 0.05$).
[1]Heat production calculated by the RQ-method.
[2]Values corrected for carbon dioxide from fermentation as suggested by Chwalibog et al. (1996).
[3]Calculated according to AFRC (1993).

3.3. Intake and excretion of fatty acids

Total FA consumption varied between groups, being higher by 28% and 17% with the C18:0 than with C12:0 and C14:0 supplementation (Table IV). The realized contents of total C12:0, C14:0 and C18:0 in the diets as consumed were 25, 22 and 34 g/kg instead of 40 g/kg. Nevertheless, C12:0 and C14:0 intakes were similar with 368 and 391 g/d, thus being comparable and dominant as FA in the respective groups. The extra intake of C18:0 (617 g/d) was clearly higher in the C18:0 supplemented group. Treatment differences in the intake of other FA were low in extent compared to the variation in the supplemented FA.

Cows excreted similar amounts of total FA with the milk, and levels were higher than the respective intakes of FA. Considerable proportions of the FA supplemented were apparently recovered in milk, accounting for 26%, 39% and 12% of the extra intake with C12:0, C14:0 and C18:0, respectively, when correcting for the average baseline levels of these FA in the respective other groups. The use of C12:0 instead of C18:0 did not significantly alter the excretion of other major FA with milk, while the use of C14:0 significantly increased the excretion of C14:1 and of C16:0 and decreased the excretion of total C18 compared to the C18:0 supplemented group. The apparent digestibility of total FA increased in the order of C18:0, C14:0 and C12:0 supplementation. The apparent digestibilities of the supplemented FA were always highest in the respective

TABLE IV Fatty acid intake and excretion of cows fed different fatty acids

Fatty acid treatment	*C12 : 0*	*C14 : 0*	*C18 : 0*	*SEM*	P-*value*
Intake [g/d]					
Total fatty acids	694.5^{b}	796.1^{ab}	964.1^{a}	52.64	< 0.01
C12:0	368.2^{a}	5.6^{b}	9.2^{b}	32.32	< 0.001
C14:0	5.0^{b}	391.3^{a}	1.6^{b}	4.52	< 0.001
C16:0	53.3^{b}	68.1^{a}	60.7^{ab}	3.33	< 0.05
C18:0	11.1^{b}	18.2^{b}	617.2^{a}	19.00	< 0.001
C14:1	5.1	5.1	5.2	0.52	0.98
C16:1	8.0	8.0	7.6	0.80	0.90
C18:1	39.1^{b}	53.1^{a}	46.2^{ab}	2.39	< 0.01
C18:2	113.9^{b}	150.9^{a}	124.8^{b}	6.06	< 0.01
C18:3	82.3	87.2	84.0	6.62	0.87
Total C18	246.4^{b}	309.4^{b}	872.1^{a}	29.94	< 0.001
Excretion with milk [g/d]					
Total fatty acids	1113.3	1175.2	1091.7	60.47	0.61
C12:0	137.2^{a}	43.1^{b}	41.5^{b}	12.04	< 0.001
C14:0	128.7^{b}	266.5^{a}	104.3^{b}	8.07	< 0.001
C16:0	289.5^{b}	372.9^{a}	280.9^{b}	20.69	< 0.05
C18:0	104.7^{b}	68.7^{c}	156.4^{a}	7.06	< 0.001
C14:1	8.2^{b}	22.8^{a}	8.1^{b}	1.20	< 0.001
C16:1	18.5	17.2	11.9	2.22	0.11
C18:1	285.5	200.1	275.1	30.87	0.14
C18:2	21.7	26.0	27.3	1.93	0.14
C18:3	7.3	5.9	7.8	0.77	0.24
Total C18	426.2^{ab}	307.1^{b}	471.1^{a}	38.98	< 0.05
Apparent digestibilities					
Total fatty acids	0.923^{a}	0.725^{b}	0.351^{c}	0.0528	< 0.001
C12:0	0.986^{a}	0.656^{b}	0.802^{ab}	0.0628	< 0.01
C14:0	0.530^{a}	0.780^{a}	− 0.764^{b}	0.2360	< 0.001
C16:0	0.789^{a}	0.565^{b}	0.531^{b}	0.0488	< 0.01
C18:0	− 0.441^{a}	− 2.375^{b}	0.114^{a}	0.5222	< 0.05
C14:1	0.565^{a}	0.280^{b}	0.360^{ab}	0.0594	< 0.05
C16:1	0.710	0.700	0.805	0.0367	0.12
C18:1	0.838^{a}	0.689^{b}	0.611^{b}	0.0403	< 0.01
C18:2	0.969^{a}	0.948^{ab}	0.925^{b}	0.0076	< 0.01
C18:3	0.989	0.987	0.986	0.0013	0.25
Total C18	0.898^{a}	0.729^{a}	0.340^{b}	0.0600	< 0.001

Mean values within the same line sharing no common superscript are significantly different ($P < 0.05$).

groups. The apparent digestibility of C18 : 0 was negative with the C12 : 0 and C14 : 0 diet, while C14 : 0 digestibility was negative in the C18 : 0 group. C12 : 0 supplementation increased digestibilities of C16 : 0, C14 : 1, C18 : 1 and C18 : 2 relative to the other groups. Regardless of the treatment, high digestibility coefficients were observed with PUFA additionally increasing with increasing numbers of double bounds. The daily faecal excretion of odd-chain FA, C15 : 0 and C17 : 0 (not given in table), was nearly the same for the C14 : 0 (2.41 and 3.82 g/d, respectively) and the C18 : 0 treatment (2.16 and 3.31 g/d) but was significantly lower with the C12 : 0 diet (1.14 and 1.63 g/d).

3.4. Milk fat characteristics

The FA composition of the milk fat was markedly altered by each of the MCFA supplemented (Table V). Supplementation increased the percentages of the respective

TABLE V Fatty acid composition of the milk [% total fatty acid methyl esters] of cows fed different fatty acids

Fatty acid treatment	*C12:0*	*C14:0*	*C18:0*	*SEM*	P-*value*
Total saturated fatty acids	68.32	75.64	68.77	1.994	0.05
C4:0	3.29	3.06	3.54	0.170	0.17
C6:0	2.48[b]	2.61[ab]	3.01[a]	0.142	< 0.05
C8:0	1.20[b]	1.34[ab]	1.59[a]	0.097	< 0.05
C10:0	2.53	3.09	3.47	0.257	0.06
C12:0	12.57[a]	3.66[b]	3.78[b]	1.037	< 0.001
C14:0	9.56[b]	22.76[a]	11.74[b]	0.685	< 0.001
C15:0	0.72[b]	1.11[a]	0.78[b]	0.068	< 0.01
C16:0	26.00[b]	31.67[a]	25.65[b]	0.872	< 0.001
C17:0	0.54[a]	0.40[b]	0.47[ab]	0.032	< 0.05
C18:0	9.31[b]	5.84[b]	14.63[a]	0.651	< 0.001
C20:0	0.13[a]	0.10[b]	0.12[a]	0.005	< 0.001
Total monoenoic fatty acids	27.76[a]	20.56[b]	27.13[a]	1.900	< 0.05
C14:1	0.75[b]	1.96[a]	0.74[b]	0.113	< 0.001
C16:1	1.64[a]	1.47[ab]	1.07[b]	0.146	< 0.05
Total C18:1	25.20[a]	17.02[b]	25.15[a]	1.822	< 0.01
Total C18:1 *cis*	23.21[a]	15.45[b]	23.96[a]	1.823	< 0.01
Total C18:1 *trans*	2.00[a]	1.57[ab]	1.20[b]	0.146	< 0.01
C18:1 *c6*	0.28[a]	0.24[a]	0.16[b]	0.019	< 0.01
C18:1 *c9*	21.35[a]	14.06[b]	22.85[a]	1.779	< 0.01
C18:1 *c11/t15*	0.69[a]	0.48[ab]	0.45[b]	0.061	< 0.05
C18:1 *c12*	0.20[a]	0.15[b]	0.15[ab]	0.114	< 0.05
C18:1 *c13*	0.14[a]	0.10[b]	0.06[b]	0.011	< 0.001
C18:1 *c14/t16*	0.31[a]	0.27[a]	0.17[b]	0.013	< 0.001
C18:1 *c15*	0.25[a]	0.16[b]	0.12[c]	0.009	< 0.001
C18:1 *t6-8*	0.20	0.18	0.18	0.016	0.56
C18:1 *t9*	0.14	0.13	0.12	0.010	0.22
C18:1 *t10/t11*	1.66[a]	1.26[ab]	0.91[b]	0.129	< 0.01
Total polyenoic fatty acids	3.22	3.27	3.60	0.146	0.17
Total C18:2	1.95[b]	2.21[ab]	2.48[a]	0.088	< 0.01
C18:2 *t9,t12*	0.16[a]	0.19[a]	0.09[b]	0.014	< 0.001
C18:2 *t9,c12*	0.08[a]	0.09[a]	0.05[b]	0.005	< 0.001
C18:2 *c9,t12*	0.35[a]	0.15[b]	0.12[b]	0.020	< 0.001
C18:2 *c9,c12*	1.37[c]	1.79[b]	2.23[a]	0.079	< 0.001
C18:2 conjugated	0.63[a]	0.56[ab]	0.42[b]	0.054	< 0.05
C18:3 *c9,c12,c15*	0.65[ab]	0.50[b]	0.70[a]	0.040	< 0.01
Total C18	37.73[a]	26.13[b]	43.39[a]	2.185	< 0.001

Mean values within the same line sharing no common superscript are significantly different ($P < 0.05$).

FA. The proportions of the SCFA (C4:0, ns; C6:0) and of other MCFA (C8:0, C10:0) were reduced by C12:0 and C14:0 supplementation. C16:0 was the predominant FA in the milk fat of all treatment groups and was highest in the C14:0 group accounting for nearly one third of total FA. In turn, C18:0 and C20:0 proportions were lowest with C14:0 supplementation. The influence of the diets on the proportions of the odd-chain FA was not consistent. While the C14:0 treatment enhanced C15:0, C17:0 was highest with the C12:0 treatment. The total saturated FA made up a proportion of 75.6% in the C14:0 group which was higher by about 7% than in the other two groups. On the other hand, the percentage of total monoenoic acids was reduced by about 7% with the C14:0 diet compared to the other treatments. In detail, total C18:1 *cis*, the predominant isomers of C18:1, were almost equal with

C12:0 and C18:0 supplementation and were lower by about 8% with C14:0. The C18:1*t10/t11* isomer was highest in the C12:0 and lowest with C18:0 group. C14:1 proportion was highest with C14:0 addition, while C16:1 was highest with C12:0. The proportions of total C18:2 and C18:3 were reduced with MCFA supplementation. C12:0 enhanced the percentage of the conjugated C18:2 whereas the effect of C14:0 was not significant. As expected, the amount of total C18 was highest in the C18:0 treatment, but there were also differences between the C12:0 and the C14:0 groups.

The DSC melting properties illustrated that milk fat was particularly slowly-melting with the C14:0 treatment (Table VI). In detail, the onset and offset temperatures as well as the total enthalpy spent and the solid fat content measured at various temperatures increased in this treatment. Differences between the C12:0 and the C18:0 treatment were insignificant.

4. DISCUSSION

In the present study, three diets differing only in the FA supplemented were compared. For different reasons (concentrate refusals with supplemented C12:0 and unintentionally low C14:0 content of the C14:0 supplemented concentrate), the intended dietary proportions were not achieved with C12:0 and C14:0. The realized intakes with C12:0 and C14:0 in the respective groups were similar but lower than with C18:0. On this basis, it has to be acknowledged that there might be a certain bias when comparing the three diets. However, since all three FA remained the predominant representatives in their respective diet, it seems to be justified to attribute most of the effects found to these FA.

4.1. Effect of lauric, myristic and stearic acid on performance

The lower feed intake found with the C12:0 treatment in every individual cow was the result of an impaired palatability since refusals exclusively consisted of concentrate which contained 80 g C12:0/kg according to analyses. Steele and Moore (1968a) also observed refusals of concentrate containing 100 g C12:0/kg in dairy cows, and

TABLE VI Melting properties of milk fat of cows fed different fatty acids

Fatty acid treatment	*C12:0*	*C14:0*	*C18:0*	*SEM*	P-*value*
Onset temperature [°C]	-34.0^{ab}	-31.9^{a}	-37.2^{b}	1.30	< 0.05
Offset temperature [°C]	33.0^{b}	36.7^{a}	32.9^{b}	0.59	< 0.001
Total enthalpy [J/g]	83.5^{ab}	89.3^{a}	75.4^{b}	2.46	< 0.01
Solid fat content [%]					
at − 20°C	95.2^{b}	97.6^{a}	93.9^{b}	0.63	< 0.01
at − 10°C	87.5^{b}	93.1^{a}	85.7^{b}	1.21	< 0.01
at 0°C	74.8^{b}	83.7^{a}	72.2^{b}	1.66	< 0.001
at 4°C	67.7^{b}	78.1^{a}	64.9^{b}	1.83	< 0.001
at 10°C	53.1^{b}	64.3^{a}	51.0^{b}	1.92	< 0.001
at 20°C	17.8^{b}	27.0^{a}	13.8^{b}	1.61	< 0.001
at 30°C	0.1^{b}	3.5^{a}	1.2^{b}	0.60	< 0.01

Mean values within the same line sharing no common superscript are significantly different ($P < 0.05$)

described that cows would not tolerate more than 53 g C12 : 0/kg concentrate. In agreement with that, Rindsig and Schultz (1974) found that dairy cows readily consume 400 g C12 : 0/d (56 g C12 : 0/kg concentrate). Feed refusals were also reported from the use of higher proportions of coconut oil or blends of coconut oil and palm kernel oil in cows (Rohr and Okubo, 1968; Rohr *et al.*, 1978). In the present study, there was no noticeable effect of C14 : 0 on feed intake, BW and milk yield. Although it cannot be excluded that, due to the low dietary proportion, refusals only did not occur with C14 : 0 because supply was as low as the voluntary intake of C12 : 0, in another experiment with sheep concentrates containing up to 150 g/kg of C14 : 0 (50 g/kg total diet) were consumed without significant refusals (Machmüller *et al.*, 2003). This suggests that really C12 : 0, which is characterized by a soapy taste, is responsible for refusals occurring in concentrates with higher proportions of coconut oil or other MCFA-rich fats.

Neither BW nor milk yield was affected by feeding C14 : 0 instead of C18 : 0 even though GE supply by the C14 : 0 diet was slightly lower due to the lower total FA content. The reduced concentrate intake in the C12 : 0 treatment seemed to have slightly reduced milk yield but less than should have resulted from the correspondingly lower energy intake. Probably body fat mobilization, known to cover approximately half of a moderate level of energy deficit for several weeks (Röhrmoser and Kirchgessner, 1982), prevented a clearer depression of milk yield in the cows receiving the C12 : 0 diet. The energy deficit also slightly affected milk protein synthesis resulting in a numerically lower milk N excretion at constant milk protein content. Steele and Moore (1968a) found a large reduction in milk yield at a constant milk fat yield with C14 : 0 while C12 : 0 treatment did not affect milk yield but clearly decreased milk fat yield. It seems that the major effects of MCFA on performance are indirect either through a reduced feed intake or through a depression of rumen fermentation, this particularly in diets low in structural fibre when also milk fat is massively depressed by the addition of the MCFA (Rohr *et al.*, 1978).

4.2. Digestive and metabolic utilization of lauric, myristic and stearic acid

Ruminants digest fats with a high efficiency. Coefficients of digestibility as high as 0.8 to 0.9 have been reported for a variety of fats, oils and FA (reviewed by Moore and Christie, 1984). Dose effects on the FA digestibility seem to be variable since reductions (Palmquist, 1991), constant levels (Hagemeister and Kaufmann, 1979) and increases (Czerkawski, 1966) were reported with increased supply of fats or FA. In the present experiment, the apparent digestibility of total FA decreased in the order of C12 : 0, C14 : 0 and C18 : 0 supplementation which is mainly explained by the high proportions of C12 : 0, C14 : 0 and C18 : 0 in the respective diets. Although in ruminants the influence of the chain length is not so pronounced as in non-ruminants (Andrews and Lewis, 1970), digestibilities of saturated FA decline from C12 : 0 to C18 : 0 (Steele and Moore, 1968b; Andrews and Lewis, 1970; present study). However, in the case of C18 : 0 the true digestibility in ruminants is much higher than the apparent digestibility because of the transformation of unsaturated C18 FA to C18 : 0 by ruminal biohydrogenation. This can even lead to apparently negative C18 : 0 digestibilities (Machmüller *et al.*, 2000). Hagemeister and Kaufmann (1979), investigating only the intestinal digestibility, found higher digestibilities for C18 : 0 than for C12 : 0 in ruminants. Therefore, it seems likely that differences in C12 : 0 and C14 : 0 digestibility

can be mainly explained by the correspondingly differences in chain length while the low C18 : 0 digestibility was the result of saturation of other C18 FA, of the higher intake and of the longer chain length. The high total tract C12 : 0 digestibility could have resulted from the ability of the rumen wall to absorb FA of short and medium chain length. Accordingly, up to 30% of dietary C12 : 0 can be absorbed from the rumen (Hagemeister *et al.*, 1979). C12 : 0 represents the borderline in chain length where absorption shifts from the rumen to the intestine. Therefore, C14 : 0 might be less digestible than C12 : 0 both in the rumen and the intestine.

Lavau and Hashim (1978) found in rats that MCFA, particularly C8 : 0 and C10 : 0, have a similar metabolic function as carbohydrates, i.e., they are extensively oxidized in the liver and less effectively incorporated into the tissue than FA with longer chain length such as C16 : 0. To our knowledge there is no other study comparing the metabolic use of MCFA and of long-chain FA (LCFA) in dairy cows, and from the present results it appears that the observations in the rats (Lavau and Hashim, 1978) may be at least partially applicable for C12 : 0 in ruminants. Indications for that are the lower respiratory quotient, suggesting higher proportions of fat being metabolically oxidized, the relatively low calculated transfer rates of supplemented C12 : 0 to milk fat and the exceptionally high k_l value when compared with C14 : 0 which was consumed to a similar amount. However, part of the effects might have resulted from the associated differences in forage-to-concentrate ratio of the C12 : 0 and the C14 : 0 group. The uncorrected k_l values corresponded well with other studies (compiled by Bergner and Hoffmann, 1996), while values corrected for carbon dioxide from the fermentation process (Chwalibog *et al.*, 1996), an adjustment rarely made, were higher.

As the amount of dietary FA transferred directly into milk fat is influenced by various factors (Palmquist *et al.*, 1993), the calculation of their true transfer rates is not possible (Wu and Palmquist, 1991). However, opposing intake and excretion nevertheless gives a measure for apparent transfer rates. These were highest for C14 : 0 (39%) compared to 26% for C12 : 0 and 9% for C18 : 0 (using the value of the C12 : 0 group as a reference). For C12 : 0 this is very similar to the 27% reported by Storry (1981) who suggested that the C12 : 0 transfer rate from feed to milk is likely to be underestimated because of a concomitant depression in intra-mammary synthesis of C12 : 0.

Apart from being directly utilized, the supplementation of the three FA influenced the excretion of other FA with the milk as was also reported earlier (Steele and Moore, 1968a). Both modification of the supplemented FA to other FA and side-effects on absorption, metabolic use and synthesis of other FA in the mammary gland may occur. The latter often represents a simple replacement of other FA by the supplemented FA (Rindsig and Schultz, 1974; Storry, 1981). Excretions of C14 : 1 were significantly increased suggesting an increased desaturase activity (Storry, 1981) whereas chain elongation of both C12 : 0 and C14 : 0 in the mammary gland can be excluded (Christie, 1979). The higher proportion of C16 : 0 in the C14 : 0 group could have been caused by the high intake of this FA because Christie (1979) even reported a reduced C16 : 0 level with C14 : 0 (and C12 : 0) supplementation. The processes occurring with the C18 FA during rumen fermentation, digestion and metabolism, including the pronounced desaturase activity of the mammary gland (Enjalbert *et al.*, 1998), makes it impossible to draw sound conclusions about what happened to the C18 : 0 supplemented. Noble *et al.* (1969) reported that the proportion of C18 : 0 and C18 : 1 significantly increased in the milk fat of cows consuming a concentrate containing 100 g C18 : 0/kg and the

proportion of C18 : 2 decreased compared to a control group receiving an unsupplemented concentrate.

4.3. Effect of lauric, myristic and stearic acid on the utilization of other nutrients

Bergner and Sommer (1994) recommended a general renouncement of feeding non-esterified FA to ruminants because of their often adverse influence on rumen fermentation and nutrient digestibility. This is in contrast to Palmquist (1991) finding no adverse effect of non-esterified FA applied to dairy cows on DM and fibre digestibilities compared to other fat sources. Although a negative effect of MCFA on gram positive rumen bacteria cannot be excluded (Galbraith *et al.*, 1971), *in vitro* counts of total rumen bacteria and total VFA concentration were not different between an unsupplemented diet and diets supplemented either with C12 : 0, C14 : 0 or C18 : 0 (Dohme *et al.*, 2001). In the same study, C12 : 0 significantly reduced ruminal degradation of NDF which is in contrast to the present lack of significant effect on total tract digestibility of CF and NDF. Machmüller and Kreuzer (1999), who also found no significant depression of fibre digestion in sheep fed coconut oil, assumed that a depressed ruminal fibre degradation *in vivo* with MCFA is presumably compensated by an increased fibre degradation in the hindgut. Furthermore, other feed constituents such as calcium, included in the mineral premix, might have reduced adverse effect of MCFA on fibre digestion by soap formation (Machmüller *et al.*, 2003). The occurrence of lower quantities of odd chain FA such as C15 : 0 and C17 : 0 in faeces of the C12 : 0 group compared to the other groups indicates a reduced microbial activity, particularly of the producers of propionate, a precursor of odd-chain FA (Wu and Palmquist, 1991). However, Emmanuel (1978) stated that C15 : 0 and C17 : 0 are preferentially formed by α-oxidation of C16 : 0 and C18 : 0, provided these FA are present in the rumen, rather than by elongation of propionate. As the daily intake of C16 : 0 and C18 : 0 was higher with the C14 : 0 and C18 : 0 diets this could also explain the elevated excretion of the odd-chain FA with faeces in these groups.

4.4. Effect of lauric, myristic and stearic acid on the fatty acid composition of the milk

Supplementation of C12 : 0, C14 : 0 and C18 : 0 resulted in clear increases of the proportions of these FA in milk fat from 4 to 12%, 10 to 23% and 7 to 15%, respectively. This supports previous findings of Rindsig and Schultz (1974) where 400 g C12 : 0/d increased C12 : 0 proportion from 3 to 19% and of Storry (1981) where 100 g coconut oil/kg concentrate elevated milk fat C12 : 0 proportion from 6 to 13%. Similarly, supplementary C14 : 0 increased its proportion in milk from 11 to 32% in the study of Christie (1979). By contrast, in the study of Rohr *et al.* (1978) there was not the least response of C12 : 0 and C14 : 0 in milk when supplemented as 500 g coconut oil/d. No explanation is obvious for this finding and also the authors gave no reasoning.

During the last decades various authors recommended that human C12 : 0 and C14 : 0 intakes and, consequently contents of milk fat, should be kept as low as possible (*e.g.* Ney, 1991; Jahreis *et al.*, 1996; Goodridge *et al.*, 2001) as both increase plasma total and LDL cholesterol concentration thus enhancing the risk of CHD in man (Williams, 2000). For this reason, feeding strategies were introduced which particularly aim to reduce MCFA (*e.g.*, Soita *et al.*, 2003). However, C12 : 0 and C14 : 0 seem to have

different modes of action and their effects on LDL and HDL cholesterol are controversially discussed (Katan *et al.*, 1994; Temme *et al.*, 1996). Apart from their potential hypercholesterolemic effects, MCFA seem to have also favourable properties. Rioux and Legrand (2001) assumed that C14:0 plays an important role in cell regulation. In turn, C12:0 and its esterified forms have antimicrobial properties, for instance against *Listeria monocytogenes*, which causes a zoonosis potentially occurring by the consumption of dairy products (Wang *et al.*, 1993), and against spores of food-borne pathogens and spoilage bacteria (Ababouch *et al.*, 1992). This may increase the hygienic quality and the shelf life of milk and milk products and suppress infections with *Listeria monocytogenes* as found in rats fed bovine milk fat (Sprong *et al.*, 1999). Furthermore, Enig (1999) recommended that foods containing C12:0 should be included in diets of HIV-infected individuals.

There were additional effects, particularly of C12:0, on minor fatty acids which either are not present in the dietary lipids at all or only in low concentrations. These minor FA include *trans*-FA and conjugated linoleic acids which have a high dietetic relevance in human nutrition. Compared with the C14:0 and C18:0 diet, the C12:0 diet increased the proportions of C18:1*t10*/*t11* and conjugated C18:2 in milk. It is assumed that the positive health effects of the conjugated linoleic acids (Williams, 2000) overrides the effect of the concomitantly increased C18:1 *trans*-FA, particularly because the major isomer formed in the rumen is considered to contribute less to the occurrence of CHD than those produced along with technological hydrogenation of vegetable oils (Willett *et al.*, 1993). Therefore, in the case of C12:0, where (in contrast to the C14:0 diet) MCFA proportion was less clearly increased and no depression in the desired total monoenoic acids (Williams, 2000) occurred, positive and negative health effects may widely compensate.

4.5. Effect of lauric, myristic and stearic acid on technological properties of milk fat

A soft milk fat is desired, particularly to enhance the spreadability of butter. This property is mainly determined by the ratio of C18:1 to C16:0. Milk fat with a ratio of < 0.6 proves to be too hard and should not be used in manufacturing of butter (Jahreis *et al.*, 1996). The C18:1 to C16:0 ratio was favourable with on average 0.98 when supplementing the diet with the C12:0 and C18:0 and also the melting properties did not differ much when feeding these two FA. For C18:0 this is explained by the conversion of C18:0 to C18:1*c9* by the delta-9 desaturase, since about 40% of C18:0 taken up by the mammary gland is desaturated and contributes to more than 50% of the C18:1*c9* secreted with milk fat (Enjalbert *et al.*, 1998). Supplementary C12:0 did not affect excretion of C18:1 and C16:0 compared to the C18:0 diet thus probably reflecting still the typical pattern of synthesis of these two FA. The additional C14:0, by contrast, reduced the C18:1 to C16:0 ratio to an unfavourably low value of 0.55 ($P < 0.05$ against the C12:0 and C18:0 group) and massively increased solid fat content at a given temperature. Some manufacturers such as bakers and confectioners often prefer a harder milk fat to achieve the desired textural characteristics of their products. In order to achieve this, attempts have been made to increase the firmness of milk fat by feeding fats characterized by high proportions of saturated FA (Fearon and Kilpatrick, 1991). According to the present results, milk fat obtained from C14:0 fed cows is particularly suitable for that purpose.

5. CONCLUSIONS

The supplementation of the two major MCFA, C12:0 and C14:0, to dairy cows appears to modify energy utilization, FA composition and melting properties of milk fat, but in a contrasting manner. C14:0, even when supplemented in a comparably low dietary proportion, had clear and often undesired effects, except for certain bakery products where a hard milk fat is required. The supplementation of C12:0 and C18:0 in dairy cow diets seems to be neutral or even favourable from a human dietetic point of view. C12:0 also appears to have a positive effect on energy metabolism of dairy cows as it improved metabolic efficiency of ME utilization. Since the major plant oils rich in MCFA, coconut oil and palm kernel oil, contain high proportions of C12:0 and C14:0, new solutions have to be found for applying only C12:0, for instance using technological production of pure C12:0 or use of oils obtained from genetically modified canola oil (Dohme *et al.*, 2000). However, apart from the low acceptance of products from genetically modified plants, the applicability of C12:0 and fats rich in C12:0 is seriously limited by the associated adverse effects on feed palatability, a problem which has to be solved when higher amounts are employed. Moreover, additional research is necessary to clarify the potentially beneficial effects of MCFA on human health.

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