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SHORT COMMUNICATION

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Relationships between the daily intake of unsaturated plant lipids and the contents of major milk fatty acids in dairy goats

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Abstract

A meta-regression of the effects of the amount of plant lipids consumed by dairy goats on the contents of some milk fat fatty acids (FA) was carried out. Fourteen peer-reviewed published papers reporting 17 experiments were used in the study. Those experiments compared control diets without added fat with diets that included plant lipids rich in unsaturated FA, summing up to 64 treatments. The results showed that increasing daily intake of plant lipids linearly reduced the contents of all medium chain saturated FA in milk fat. Moreover, it was observed that the longer the chain of the milk saturated FA, the greater the negative effect of the plant lipid intake on their contents. On the other hand, the contents of stearic acid and the sum of oleic, linoleic and α-linolenic acids in milk fat linearly increased as daily plant lipid intake rose. The results obtained corroborate previous reports on the effects of feeding dairy goats with increasing amounts of unsaturated plant lipids on milk FA profile.

Additional key words: meta-regression; dairy; fat; diet; ruminants.

Abbreviations used: DM (dry matter); FA (fatty acid); RMSE (root mean square error); UFA (unsaturated fatty acid).

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Some papers have reported the effect of adding different amounts of unsaturated plant lipids to dairy goat diets on their milk fat fatty acid (FA) contents (Mir *et al.*, 1999; Schmidely *et al.*, 2005; Nudda *et al.*, 2006; Martínez Marín *et al.*, 2012), but few of them have quantitatively related the observed responses to the daily lipid intake. Martínez Marín *et al.* (2012) observed significant linear effects on the contents of the major FA in milk fat when fed dairy goats with increasing amounts (0, 32, 48 or 66 g/d) of three differently unsaturated plant lipids; however, they did not derive quantitative relationships. On the other hand, the amounts of unsaturated plant lipids supplied to dairy goats in the literature cover a much wider range, *i.e.* 15 to 207 g/d (Nudda *et al.*, 2006; Ollier *et al.*, 2009). Therefore, a meta-analysis of published research data could help to relate the observed responses of milk fat FA contents to the amount of unsaturated plant lipids fed to dairy goats, as an alternative to the scarcity of papers on the matter. Meta-analysis is a statistical tool used to objectively review prior published results even if the researches differ in their methodology. Meta-regression is a type of meta-analysis that allows integrating quantitative findings to formulate models that best explains the observations (St-Pierre, 2001; Sauvant *et al.*, 2008).

The aim of this paper was to put published research data on feeding dairy goats with unsaturated plant lipids to meta-regression, in order to quantify the relationship between the amount of lipids consumed and the contents of some FA in milk fat.

Research papers on the inclusion of unsaturated plant lipids in dairy goat diets were searched in bibliographic databases (ISI Web of Science, Scopus, PubMed, Google Scholar) using the following keywords: fats, goats, milk fat and fatty acids. Studies were selected if they compared a control diet with no added fat with one or more treatments that included one unprotected fat source rich in unsaturated FA. A total of 14 peer-reviewed research papers with 17 experiments and 64 treatments fulfilled the requirements (Suppl. Table S1 [pdf online]).

Treatments were coded either as NOLIP when the diet contained no added fat, or as LIP if the diet included extra fat, which could be supplied as oils and oilseeds, either rich in oleic or linoleic or α-linolenic acids. Percentages of added fat in each treatment, dry matter (DM) intake and several other factors related to the fat sources studied, the animals and the diets used, and the experimental design were recorded and stored in a Microsoft Excel spreadsheet. Variables studied were the milk fat contents of short and medium chain saturated FA (from C4:0 to C16:0), stearic acid, and the sum of oleic, linoleic and α-linolenic acids (C18 UFA). Milk fat contents of neither oleic, linoleic and α-linolenic acids, accounted for separately from each other, nor *trans*-10 C18:1, *trans*-11 C18:1, and *cis*-9,*trans*-11 C18:2 were included in our study because their contents in ruminant milk fat are known to specifically depend on the percentage of oleic, linoleic and α-linolenic acids in the plant lipids supplied (Martínez Marín *et al.*, 2013b) and this factor could not be considered in the present study, due to the low number of published experiments.

MIXED procedure of SAS 9.1 (SAS Institute Inc., Cary, NC, USA) was used in the statistical analyses. Firstly, we compared NOLIP and LIP diets to rule out diet composition as a source of interference. The linear mixed model used was (Sauvant *et al.*, 2008):

$$Y_{ijk} = \mu + S_i + T_j + ST_{ij} + e_{ijk},$$

where Y_{ijk} is the dependent variable, μ is the overall mean, S_i is the random effect of the i^{th} experiment, T_j is the fixed effect of the j^{th} level of treatment (NOLIP and LIP), ST_{ij} is the random interaction between the i^{th} experiment and the j^{th} level of treatment, and e_{ijk} is the residual error. Next, a regression analysis (meta-regression) was conducted to study the relationship between the daily intake of supplementary fat and the FA contents in milk fat. The graphical analysis of data showed that the relationships between the FA contents in milk fat and the daily fat intake, if it existed, were linear, so only this type of relationship was investigated. For each equation obtained, the root mean square error (RMSE) and the coefficient of determination (R^2) were calculated. The linear mixed model used was (Sauvant *et al.*, 2008):

$$Y_{ij} = B_0 + S_i + B_1X_{ij} + b_iX_{ij} + e_{ij},$$

where Y_{ij} is the dependent variable, B_0 is the overall intercept, S_i is the random effect of the i^{th} study, B_1 is the overall regression coefficient of Y on X, X_{ij} is the value of the continuous predictor variable (fat intake, fixed effect), b_i is the random effect of the experiment on the regression coefficient of Y on X, and e_{ij} is the residual error. The data were weighed with the square root of the number of animals used in each treatment using the WEIGHT statement.

Twenty two out of 64 treatments corresponded to control diets without added fat, and 16, 16 and 10 corresponded to diets enriched in oleic acid, linoleic acid and α-linolenic acid, respectively. Supplementary lipids were fed as free oils (30 treatments) and oilseeds (12 treatments). Supplementary fat was (mean ± SD and range) 3.43 ± 1.420 [0.80-6.50] % dry matter, or 74.3 ± 40.40 [15.0-207.0] g/d, or 1.30 ± 0.630 [0.25-3.45] g/kg body weight. Experiments carried out with dairy goats to investigate the effects of unsaturated plant lipid supplementation on milk fat FA contents are limited in number, compared with those carried out with dairy cows. Because of the few number of available treatments in our meta-regression, it was not possible to study the effects of the type of plant lipids supplied (*i.e.* rich in oleic, linoleic or α-linolenic acids) or the fat sources used (oils *vs.* oilseeds). On the other hand, the interference due to diet composition, if any, should be minimal because there were no differences between NOLIP and LIP treatments, except for the extra fat added (Table 1).

In the present study, the contents of C4:0 and C6:0 in goat milk fat were not reduced with increasing daily fat intake. Furthermore, the negative effects of plant lipid intake on the FA synthesized *de novo* in the mammary gland were clear from C8:0 upwards. Indeed, the slope of the C10:0 equation was ten-fold higher than that of the C8:0 equation (Table 2). Although there are not published meta-regressions that allow a direct comparison, in several experiments carried out with dairy cows (Mustafa *et al.*, 2003; Collomb *et al.*, 2004; Akraim *et al.*, 2007; Liu *et al.*, 2008; Chilliard *et al.*, 2009) and ewes (Mele *et al.*, 2006; Zhang *et al.*, 2006; Gómez-Cortés *et al.*, 2008; Hervás *et al.*, 2008, Bodas *et al.*, 2010) fed similar amounts of unsaturated plant

Table 1. Diet composition (percent on dry matter basis)

	Treatments				*p*
	NOLIP	**SEM**	**LIP**	**SEM**	
Forage	42.91	2.126	44.01	1.480	0.68
Crude protein	16.19	0.137	16.48	0.100	0.09
Neutral detergent fibre	35.51	0.660	34.92	0.460	0.47
Added fat	–	–	3.43	0.219	–

NOLIP: diets with no added plant lipids; LIP: diets added with plant lipids rich in unsaturated fatty acids. SEM: standard error of the mean.

Table 2. Linear regression equations of the relationships between the intake of unsaturated plant lipids (g/d) and the fatty acid contents (% total fatty acids) in milk fat of dairy goats

Fatty acids	Parameter estimates						RMSE	R^2
	Intercept	SEM	*p*	Slope	SEM	*p*		
C4:0	2.12	0.217	<0.001	0.0015	0.00033	<0.001	0.60	0.80
C6:0	2.42	0.174	<0.001	–0.0005	0.00044	0.250	0.26	0.95
C8:0	2.85	0.201	<0.001	–0.0021	0.00070	0.006	0.41	0.91
C10:0	10.14	0.324	<0.001	–0.0205	0.00253	<0.001	1.05	0.87
C12:0	5.08	0.183	<0.001	–0.0185	0.00182	<0.001	0.66	0.86
C14:0	11.24	0.253	<0.001	–0.0336	0.00330	<0.001	0.59	0.96
C16:0	30.56	0.782	<0.001	–0.1053	0.01196	<0.001	2.75	0.90
C18:0	6.93	0.297	<0.001	0.0591	0.00922	<0.001	1.78	0.89
C18 UFA	18.76	0.909	<0.001	0.0567	0.01020	<0.001	2.60	0.76

C18 UFA: sum of oleic, linoleic and α-linolenic acids. SEM: standard error of the mean. RMSE: root mean square error. R^2: coefficient of determination.

lipids (between 1 and 3 g/kg body weight), the negative effects on *de novo* synthesized FA are clearly observed from C6:0 and C8:0. Also, Glasser *et al.* (2008) found out that lipid supplementation to dairy cows, resulting in an increase of FA with 18 atoms of carbon in duodenal flow, linearly decreased the yield of C4:0 to C16:0 in milk. These differences suggest that dietary unsaturated plant lipids could have dissimilar effects on rumen digestion or lipid mammary metabolism in dairy cows, goats and ewes, as pointed out by Chilliard *et al.* (2003) and Sanz-Sampelayo *et al.* (2007).

On the other hand, Hansen *et al.* (1984), working *in vitro* with goat mammary cells, proposed that a greatly enhanced supply of long chain FA could inhibit the incorporation of *de novo* synthesized FA into triacylglycerol, owing to competition for the diacylglycerol acyltransferase, which in turn would decrease *de novo* synthesis of FA. Bernard *et al.* (2009a) found that the increase in long chain FA captured by the mammary gland reduced the activity of the enzymes involved in FA synthesis in the udder. Furthermore, it has been previously observed, working *in vitro* with mammary cells, that lowering the ratio acetyl-CoA carboxylase to FA synthetase modifies the pattern of synthesized FA towards those of shorter chain (Bauman & Davies, 1974). In agreement with that, the values of the slopes were increasingly higher in the regression equations obtained in the present work for C8:0, C10:0, C12:0, C14:0 and C16:0, to such extent that the value of the slope in the C16:0 equation was four-fold higher than the average of the slopes in the C10:0, C12:0 and C14:0 equations (Table 2, Fig. 1), *i.e.* the longer the chain of the saturated milk FA, the greater the negative effect of the intake of high quantities of unsaturated plant lipids. On the other hand, from the equations in Table 2, it was calculated that the average contents of medium chain saturated FA in milk fat were lowered more than 60% in the treatments with the highest fat intakes compared with no added lipid ones. Since medium chain saturated FA consumption is considered a risk of cardiovascular disease in people (Ulbricht & Southgate, 1991), the marked reduction of their content in the milk fat is positive from the point of view of human health.

Linear increases in the milk fat contents of both C18:0 and C18 UFA due to the increments in daily fat intake (Table 2, Fig. 1), can be explained by the higher dietary supply of long chain unsaturated FA. Any unsaturated FA of 18 atoms of carbon present in the rumen can be a source of stearic acid through biohydrogenation, thus increasing the availability of preformed stearic acid to the udder. Again, the increase of C18 UFA contents in milk fat was likely due to dietary

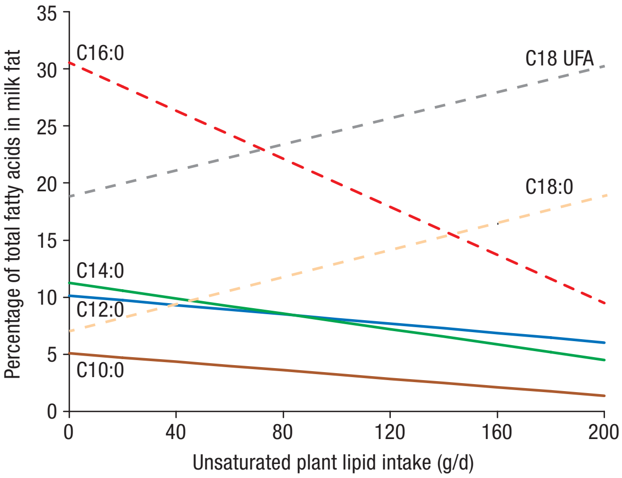

Figure 1. Relationship between daily intake of unsaturated plant lipids and the contents of major fatty acids in goat milk fat. C10:0, capric acid; C12:0, lauric acid; C14:0, myristic acid; C16:0, palmitic acid; C18:0, stearic acid; C18 UFA, sum of oleic, linoleic and α-linolenic acids.

unsaturated FA that escaped unchanged from the rumen, although in the case of oleic acid, it could be also due to Δ-9 desaturation of stearic acid in the mammary gland (Chilliard & Ferlay, 2004). From the equations in Table 2, it can be calculated that the increments of C18:0 and C18 UFA contents in milk fat as daily fat intake increased did not account for the lessening of medium chain saturated FA contents, which indicates that the contents of other FA, probably *cis* and *trans* mono- and polyunsaturated FA from rumen metabolism of dietary FA, were also increased in milk fat in response to plant lipid supplementation (Chilliard *et al*., 2007).

In conclusion, the meta-regression carried out in this work allowed to obtain quantitative relationships between the amount of unsaturated plant lipids consumed by dairy goats and the changes in the contents of some milk FA. Our results corroborate that dietary unsaturated plant lipids have a more pronounced negative effect on medium chain saturated FA contents as their chain length increases. The milk fat contents of C18:0 and C18 UFA were increased as daily fat intake rose, but the increments observed did not account for the lessening of medium chain saturated FA contents.

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