Literature review

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Fat addition in the diet of dairy ruminants and its effects on productive parameters¤

Adición de grasa en la dieta de rumiantes lecheros y sus efectos sobre parámetros productivos

Efeito da adição de gordura à dieta de ruminantes leiteiros sobre os resultados produtivos

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Summary

This review analyzes the current knowledge on the effects of fat supplementation in dairy ruminant diets. Research conducted on dairy cows and goats shows that dry matter intake decreases when diets contain extra fat due to a negative effect on digestibility. In dairy cows dry matter intake can be also decreased by gut peptides released in response to extra fat. This effect has not been observed in ewes and goats. Milk yield increases in dairy cows, ewes, and goats in a curvilinear manner with increasing amounts of dietary fat. When fat supply is low, the increase in milk yield is probably caused by a higher energy intake. However, milk yield decreases when fat supply is high, which may be related to diminished energy availability for milk production due to negative effects on rumen digestion and/or dry matter intake. Unprotected lipids negatively impact milk fat content in dairy cows, but not in dairy ewes and goats; negative effects of supplemental lipids on milk protein content observed in dairy cows and ewes has not been observed in dairy goats.

Key words: *digestibility, lipids, milk, voluntary intake.*

Resumen

Esta revisión examina la información actual sobre el efecto de añadir fuentes de grasa a la dieta de hembras rumiantes lecheras. Estudios con vacas y cabras han demostrado que el consumo de materia seca se reduce cuando la grasa extra incluida en la dieta tiene un efecto negativo sobre la digestibilidad. En vacas, el consumo también puede reducirse por efecto de la grasa extra sobre la secreción de mediadores hormonales en el intestino. Este efecto no ha sido demostrado en ovejas y cabras. En vacas, ovejas y cabras, la respuesta de la

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producción de leche a la inclusión de cantidades crecientes de lípidos suplementarios en la dieta es curvilínea: cuando el aporte de grasa es bajo, el incremento de la producción puede explicarse por un mayor consumo de energía. Por el contrario, la disminución de la producción cuando el consumo de grasa es elevado puede relacionarse con la reducción de la energía disponible debido al efecto negativo sobre la digestión ruminal y/o el consumo de materia seca. La adición a la dieta de lípidos no protegidos no tiene efectos negativos sobre el contenido de grasa láctea en ovejas y cabras, pero sí en vacas. El efecto negativo de los lípidos suplementarios sobre el contenido de proteína láctea en vacas y ovejas no ha sido descrito en cabras.

Palabras clave: *consumo voluntario, digestibilidad, leche, lípidos.*

Resumo

Nesta revisão se examina as informações atuais sobre o efeito da adição de fontes de gordura nas dietas de ruminantes (fêmeas leiteiras). Estudos com vacas e cabras têm demonstrado que o consumo de matéria seca é reduzido quando o excesso de gordura na dieta promove efeito negativo sobre a digestibilidade. Em vacas, o consumo também pode ser reduzido pelo efeito da gordura suplementar sobre a secreção de mediadores hormonais no intestino. Este efeito não foi demonstrado em ovelhas e cabras. Em vacas, ovelhas e cabras a resposta da produção de leite pela inclusão de quantidades crescentes de gordura suplementar na dieta é curvilínea: quando a suplementação de gordura é baixa, o aumento da produção pode ser explicado pelo aumento do consumo de energia. Por outro lado, a diminuição da produção de leite quando a ingestão de gordura é alta pode ser relacionada com a redução da energia disponível, devido ao efeito negativo sobre a digestão ruminal e/ou o consumo de matéria seca. A adição de lipídios não protegidos na dieta não tem efeitos negativos sobre o conteúdo de gordura do leite em ovinos e caprinos, tendo efeito apenas no leite da vaca. O efeito negativo de lipídios suplementares sobre o teor de proteínas lácteas em vacas e ovelhas não tem sido descrito em caprinos.

Palavras chave: *consumo voluntário, digestibilidade, leite, lipídios.*

Introduction

Interest has recently increased on improving fatty acids profile of milk fat by including appropriate fat sources in dairy ruminant diets. The aim is to reduce the content of medium chain saturated fatty acids (FA), which have a hypercholesterolemic effect, and increase the fatty acids considered beneficial, such as polyunsaturated FA of the n-3 series and rumenic acid (cis-9,trans-11 18:2) in milk fat (Lock and Bauman, 2004). Oilseeds and their oils, whether protected or unprotected from rumen digestion, seem to be suitable fat sources (Ashes *et al.*, 1997; Chilliard *et al.*, 2001).

On the other hand, fat sources can have negative effects on dry matter intake (DMI) (Chilliard *et al.*, 1993), fibrous carbohydrate digestibility (Sauvant and Bas, 2001), or milk composition (Doreau and Chilliard, 1992; Wu and Huber, 1994). These effects should be taken into account when attempting to improve milk FA profile.

The aim of the present paper was to review the effects of the addition of fat sources to the diet of dairy cows, ewes, and goats on DMI, milk production, and milk composition.

Effect of dietary lipids on dry matter intake

Data in tables 1 and 2 show that inclusion of fat in the diet negatively affects cows' DMI. The magnitude of this effect depends on the fat source; the effect tends to be greater when the dietary forage is corn silage. On the other hand, most research on ewes and goats has not shown that fat source negatively affects DMI (Tables 3 and 4). The reduction of DMI after dietary fat inclusion may be a result of 1) an increase in ruminating time due to negative effects on rumen digestion; 2) a slowdown of rumen emptying due to a metabolic effect of long chain FA (Chilliard *et al.*, 1993). In both situations a satiety effect due to rumen replenishment could occur.

The relationship between digestion and DMI is difficult to establish because there is a scarcity of publications in this area. Murphy *et al.* (1987) did not observe differences in DMI although rumen dry matter digestibility was lower in diets with 2.4% and 4.7% extra fat compared with a control diet (46.3%, 44.4%, and 52.1%, respectively).

Table 1. Effect of fat source on dry matter intake, milk yield, and milk composition of dairy cows, expressed as the difference with the control treatment.

	Extra fat intake (g/d)	Dry matter intake (kg/d)	Milk (kg/d)	Fat (g/kg)	Protein (g/kg)
By origin and processing[1]					
Animal fat (22)	688	-0.7*	+0.5	-1.4	-0.6*
Encapsulated animal fat (26)	941	-1.3*	+1.0*	+4.0*	-1.8*
Calcium salts of palm oil fatty acids (29)	593	-0.6*	+0.9*	+0.4	-1.2*
Oilseeds (34)	538	-0.5*	+0.3	-0.9*	-0.4*
Plant oils (8)	573	-1.1*	-0.6	-2.8*	-0.9
Encapsulated plant oils (26)	693	-1.1*	0.0	+6.4*	-0.8
By saturation degree[2]					
Saturated (17)	na	-0.9	+1.08*	+1.8*	-0.3
Unsaturated (8)	na		+0.73*	-3.5*	-1.1*
Meta-analysis (25)[3]	663	-1.2*	-0.4	0.0	0.0

[1]From Chilliard *et al.* (1993), Chilliard and Ollier (1994), and Chilliard *et al.* (2001). [2]From Schroeder *et al.* (2004). [3]Eugène *et al.* (2008). *Significant difference $p<0.05$. na: not available. In parenthesis: number of observations.

Table 2. Effect of fat source and forage type on dry matter intake, milk yield, and milk composition of dairy cows, expressed as the difference with the control treatment[1].

	Diet inclusion (% DM)	Dry matter intake (kg/d)	Milk (kg/d)	Fat (g/kg)	Protein (g/kg)
Soybean					
Corn silage (5)	12	-0.7	+0.9	-3.3	-1.0
Corn silage & alfalfa hay (6)	17	+0.1	+2.2*	-2.1	-1.0*
Corn silage & alfalfa silage (2)	18	-1.2	+1.1	+1.3	-1.8
Alfalfa silage or haylage (5)	16	0.0	+3.1*	+0.8	-0.6
Cottonseed					
Corn silage (15)	16	-0.9	0.0	-2.1*	-0.2
Alfalfa hay (11)	17	0.0	+0.1	+3.9*	-0.7*
Corn silage & bermudagrass hay (1)	15	+0.2	+0.4	+4.1*	-1.1
Corn silage & alfalfa hay (4)	19	0.0	+0.2	+2.9	-1.1*
Tallow or yellow grease					
Corn silage (1)	5.0	-2.4	-2.4	-6.7	-0.1
Corn silage & alfalfa hay (6)	4.5	-0.1	+0.4	-1.0	0.0
Alfalfa hay (4)	3.1	+0.9	+1.8	-0.7	-0.9
Alfalfa haylage (2)	5.0	+0.2	+0.7	+3.1	+0.2
Rye-grass silage (6)	5.4	-0.9*	+1.1*	+3.7*	-1.8*

[1]From Smith and Harris (1992). *Significant difference $p<0.05$. In parenthesis: number of observations.

On the contrary, Pantoja *et al.* (1994) observed a linear reduction of organic matter intake (19.4 kg/d to 16.6 kg/d) combined with a linear decrease of neutral detergent fiber (NDF) rumen digestibility (from 51.4% to 43.8%), presumably due to the degree of unsaturation of the added fat. Regarding research work on cows' total tract digestibility, Martin *et al.* (2008) observed that a decrease of 10.1% in acid detergent fiber (ADF) digestibility was parallel to a drop of 3.1 kg/d in DMI. However, organic matter total tract digestibility dropped by 18% without affecting DMI, according to Beauchemin *et al.* (2009). The relationship between decreased total tract NDF digestibility and reduced

DMI is also not evident in goats. Silva *et al.* (2007) observed that including soybean oil in the diet decreased NDF digestibility by 10% and reduced DMI by 0.3 kg/d compared with results from a control diet, although including ground soybeans decreased DMI by the same amount without affecting NDF digestibility.

The metabolic effect of fat source on DMI has been studied in cows through abomasal infusion experiments using oils and free FA. Free FA addition with increasing unsaturation showed a greater impact on DMI. Litherland *et al.* (2005) observed a linear reduction of DMI with infusions of unsaturated FA triacylglycerols and the corresponding free FA into the abomasum; the reduction was greater with the latter. This effect increased with the amount infused: 200 g/d, 400 g/d, and 600 g/d of free FA or triacylglycerols infused lowered the DMI 3.8 kg/d, 5.5 kg/d, and 10.6 kg/d or 1.1 kg/d, 2.6 kg/d and, 4.4 kg/d, respectively, compared with the intake observed for the control treatments (19.8 kg/d and 22.4 kg/d, respectively).

The effect of the degree of unsaturation was investigated by Bremmer *et al.* (1998), who infused 450 g/d of five mixtures of differently unsaturated fat sources into the abomasum (18:1 + 18:2 + 18:3 = 70 g/d, 187 g/d, 200 g/d, 257 g/d, and 384 g/d) and observed that DMI dropped from 1.2 kg/d with the more highly saturated fat mixture to 3.7 kg/d with the less saturated one, compared with intake observed for the control treatment (22.8 kg/d). It has been suggested that the observed negative effect may be due to secretion of unidentified chemical mediators as a response to the flow of fat into the duodenum. Litherland *et al.* (2005) did not observe changes in plasma cholecystokinin concentration as a result of fat abomasal infusion, but DMI reduction was significantly related to the increase of plasmatic concentration of glucagon-like peptide-1. Harvatine and Allen (2005) pointed out that the reduction of DMI observed when including unsaturated FA-rich fat into the diet may be related to a satiety effect of decreasing digestive motility as a result of intestinal peptide secretion.

Experiments similar to those reported in cows have not been published with ewes or goats. In the paper by Pérez Alba *et al.* (1997), feeding extra fat (120 g/d of calcium salts of olive oil FA or 1.3 g extra fat/kg live weight) did not lower DMI. In studies by Teh *et al.* (1994) and Brown-Crowder *et al*. (2001) increasing amounts of extra fat included in the diet resulted in a trend towards reduced DMI with the highest level used in each experiment (9% calcium salts of palm oil FA and 6% tallow, respectively). The daily fat intake with those levels (3.6 g/kg and 2.4 g/kg live weight, respectively) was higher than the infused amount of triacylglycerols and unsaturated FA (0.3 g/kg live weight), which reduced DMI in the work of Litherland *et al.* (2005).

Effects of dietary lipids on milk production

Diets with added fat generally increase milk production compared with a control diet without added fat in cows, ewes, and goats (Tables 1, 3, and 4). In cows, the increase is greater when given encapsulated animal fats or calcium salts of palm oil FA and when the saturation degree is higher (Table 1). From the information presented in tables 3 and 4 it is not possible to establish which type of fat source elicits the highest milk production response in ewes and goats. As a rule, the relationship between milk production and amount of extra fat included into the diet is curvilinear in the three species: production rises with increasing amount of fat to a maximum and decreases from a certain level of inclusion (Chilliard *et al.*, 1993; Brown-Crowder *et al.*, 2001; Gargouri *et al.*, 2006).

Increase in milk production when the dietary inclusion of extra fat is low could be explained by a higher energy concentration of the feed consumed. A straight substitution of 3% plant oil for the same amount of corn in a diet with 1.55 Mcal NEl/kg DM amounts to a 7% increase in energy concentration and a higher energy consumption if DMI remains unchanged. In fact, cow data (Table 1) show that the increase in energy consumption offset the observed reduction in DMI, with few exceptions.

Table 3. Effect of different fat source on dry matter intake, milk yield, and milk composition of dairy ewes, expressed as the difference with the control treatment.

Author	Fat source	Diet inclusion (% DM)	Dry matter intake (kg/d)	Milk (kg/d)	Fat (g/kg)	Protein (g/kg)
Cieslak *et al.* (2010)	Rapeseed oil	3.5	+0.1	+0.1*	-1.0	-1.0
Cieslak *et al.* (2010)	Rapeseed oil	7.0	+0.1	+0.1*	-3.0	2.0
Gómez-Cortés *et al.* (2008b)	Olive oil	6.0	+0.1	+0.2*	-1.2	-1.9
Gómez-Cortés *et al.* (2008a)	Soybean oil	6.0	+0.3	-0.0	-3.2	-5.4
Mele *et al.* (2006)	Soybean oil (75% forage)	4.0	-0.0	+0.0*	+0.6	-1.6*
Mele *et al.* (2006)	Soybean oil (60% forage)	4.0	+0.0	+0.0*	+0.5	-2.9*
Hervás *et al.* (2008)	Sunflower oil	6.0	+0.1	+0.1	+4.8*	-3.0
Cieslak *et al.* (2010)	Linseed oil	3.5	+0.1	+0.1*	-1.0	-1.0
Cieslak *et al.* (2010)	Linseed oil	7.0	+0.1	+0.1*	-1.0	-1.0
Zhang *et al.* (2006)	Sunflower seed	5.9	na	-0.0	-2.6*	-1.1*
Zhang *et al.* (2006)	Linseed	6.7	na	+0.1*	-1.5	-0.5
Casals *et al.* (2006)	Calcium salts of palm oil fatty acids	4.2	+0.2	-0.0	+23.9*	0.0
Pérez-Alba *et al.* (1997)	Calcium salts of olive oil fatty acids	7.0	+0.2*	+0.2	+3.2	-2.5*
Mierlita *et al.* (2010)	Calcium salts of sunflower oil fatty acids	6.0[a]	-0.4*	+0.1*	+1.8*	+1.3

[a]Included in the concentrate. *Significant difference $p<0.05$. na: not available.

Table 4. Effect of different fat sources on dry matter intake, milk yield, and milk composition of dairy goats, expressed as the difference with the control treatment.

Author	Fat source	Diet inclusion (% DM)	Dry matter intake (kg/d)	Milk (kg/d)	Fat (g/kg)	Protein (g/kg)
Brown-Crowder *et al.* (2001)	Partially hydrogenated tallow	4.5	+0.6*	+0.6*	+5.4*	+1.8*
Mir *et al.* (1999)	Rapeseed oil	3.0	0.0	+0.2	+9.2*	-0.3
Bernard *et al.* (2005)	High oleic sunflower oil	3.6	-0.1*	-0.1	+7.4*	0.0
Fernandes *et al.* (2008)	Cottonseed oil	5.0	na	-0.1*	+11.0*	+1.9
Bouattour *et al.* (2008)	Soybean oil	2.5	-0.0	-0.1	+6.7*	+0.1
Silva *et al.* (2007)	Soybean oil	4.5	-0.3*	-0.5	+0.7	+2.4
Mele *et al.* (2008)	Soybean oil (63% forage)	4.0	+0.0	+0.23*	2.2*	-0.3
Mele *et al.* (2008)	Soybean oil (35% forage)	4.0	0.0	-0.0	+2.2*	-0.3
Fernandes *et al.* (2008)	Sunflower oil	5.0	na	-0.1	+5.9	+1.4
Chilliard *et al.* (2003)	Sunflower oil	3.4	na	+0.3	+5.2*	+1.0
Ollier *et al.* (2009)	Sunflower oil	4.4	+0.03	+0.05	+6.1*	+0.3
Chilliard *et al.* (2003)	Linseed oil	3.4	na	+0.3	+3.1*	+2.4*
Ollier *et al.* (2009)	Rapeseed	14.6	+0.07	-0.41*	+6.0*	+0.4
Chilliard *et al.* (2003)	Sunflower seed	6.9	na	+0.3	+5.8*	+1.9*
Chilliard *et al.* (2003)	Soybean	15.5	na	+0.5	+4.1*	+1.5
Silva *et al.* (2007)	Soybean	22.4	-0.3*	-0.7*	-3.9	+2.1
Chilliard *et al.* (2003)	Linseed	8.9	na	+0.1	+6.0*	+2.8*
Bernard *et al.* (2005)	Protected linseed	11.2	-0.1*	-0.2*	+6.6*	+1.2*
Rapetti *et al.* (2002)	Calcium salts of palm oil fatty acids	4.7	-0.1	-0.1	+10.2*	+1.0
Silva *et al.* (2007)	Calcium salts of palm oil fatty acids	5.1	-0.0	-0.4	+0.9	+1.8

*Significant difference $p<0.05$. na: not available.

The reduction of milk production when high dietary fat supplement is provided could be related to a combined negative effect on digestion and DMI. In studies by Martin *et al.* (2008) using cows, and Silva *et al.* (2007) with goats, milk yield reduction of animals fed diets with added fat (5.7% in the diets of the first study, and 4.5% in those of the second) compared with the animals fed the control diet without added fat (20.8 kg/d and 18.9 kg/d *vs.* 23.0 kg/d, and 1.8 kg/d and 1.5 kg/d *vs.* 2.2

kg/d, respectively) was parallel to a simultaneous decrease of fibrous carbohydrate digestibility and DMI. However, Maia *et al.* (2006a, 2006b), working with goats, observed a 24% reduction in NDF digestibility when the diet included 5.1% of either rice, rapeseed, or soybean oils, but DMI and milk production were no lower than those of the control diet without added fat. Also, Beauchemin *et al.* (2009) observed that including 4.2% or 3.7% extra fat of sunflower or flax seeds in diets for cows reduced organic matter digestibility by 19% and 9%, respectively, compared with a control diet which included 3.1% fat from calcium salts of palm oil FA, but the DMI and milk production were not different between the three diets. These reports support that increasing energy concentration of the diet by fat inclusion can offset the reduced digestibility if DMI is unaffected.

Effect of dietary lipids on milk fat

In cows, the effect of fat source on milk-fat content depends on rumen digestion, subsequently related to the degree of protection of fat sources used by rumen microorganisms, and their processing and unsaturation degree (Doreau and Chilliard, 1992). Regarding protected fats (Table 1), calcium salts of palm oil FA increase milk fat content less than encapsulated plant oils because the former also increase milk production causing a dilution effect. In the non-protected fat sources group (Table 1) plant oils and animal fats reduce milk fat content; conversely, as a rule the effect of the oilseeds is negative with exceptions depending on their processing and unsaturation degree. Extruded oilseeds reduce milk fat content more frequently than when oilseeds are untreated or treated in other ways. Gonthier *et al.* (2005) observed a 0.26% reduction in milk fat content when they included 12.7% extruded linseed in a control diet, but fat content increased 0.20% and 0.14% when the same linseed was raw or micronized, respectively. Regarding saturation level, Ortiz *et al.* (1998) observed that high-oleic acid sunflower seeds (80% oleic acid in true fat) did not affect milk fat content as opposed to regular sunflower seeds (65% linoleic acid in true fat), which saw a reduction of 0.31%. Casper *et al.* (1988) obtained similar results and pointed out that negative results could be due to the effect of polyunsaturated FA in regular sunflower seeds on rumen fiber digestion, which would reduce acetate production in the rumen.

The negative effect of non-protected fat sources on milk fat content of cows is modulated by their inclusion rate and the main source of forage. Dhiman *et al.* (2000) observed a quadratic increase in milk fat content (3.44%, 3.60%, 3.56%, 2.86%, and 2.93%) as a response to growing levels of soybean oil included in the diet (control without oil, 0.5%, 1%, 2%, and 4% oil), which suggests there is a limit in the capacity of rumen cellulolytic bacteria to hydrogenate the oil consumed and to lessen the toxic effect of unsaturated FA on their growth. On the other hand, literature points out that a milk fat reduction is more likely when non-protected fat sources are included in diets based on corn silage but the reduction decreases with other forages, specially when alfalfa hay totally or partially replaces corn silage (Table 2).

The addition of fat sources of different type and origin (animal, plant, processed or whole oilseeds, calcium salts) to the diet of ewes and goats generally increases milk fat content (Tables 3 and 4) as opposed to dairy cows. In those species, milk fat percentage increases linearly when growing levels of the fat source are included in the diet (Teh *et al.*, 1994; Rotunno *et al.*, 1998; Brown-Crowder *et al.*, 2001; Casals *et al.*, 2006). In ewes, the increase of milk fat content is greater at the beginning than at the end of lactation. From the work by Pérez-Alba *et al.* (1997) and Casals *et al.* (2006) it can be calculated that the increase during the suckling period (up to 35 days of lactation) is 6.2 ± 4.1 g of fat/kg of milk higher than in the milking period. On the contrary, the response in goats is bigger from 150 days in milk than in the first 3 months of lactation: 1.0 ± 0.2 g of fat/kg of milk (Mir *et al.*, 1999; Rapetti *et al.*, 2002; Bernard *et al.*, 2005) versus 0.6 ± 0.1 g of fat/kg of milk (Teh *et al.*, 1994; Brown-Crowder *et al.*, 2001; Bouattour *et al.*, 2008).

Regarding the relationship between extra fat and forage in the diet, Mele *et al.* (2006) did not observe interaction between extra fat and percentage of forage (75% or 60%) on milk fat content of ewes.

However, Reynolds *et al.* (2006) observed that milk fat content tended to increase when 3% of a 2:1 combination of soybean-algae oils was included in a diet based on alfalfa haylage, but tended to decrease when the forage was corn silage (+13.8 g/kg *vs.* -11.7 g/kg, respectively). Chilliard and Ferlay (2004) showed that the increase in goat milk fat is lower when linseed or high oleic sunflower oils are included in corn silage based diets compared to alfalfa hay (1.5 g/kg *vs.* 6.3 g/kg, respectively).

Different digestive and metabolic causes have been advanced to explain the negative effect of non-protected fat sources on cow's milk fat content. Glasser *et al.* (2007) suggested that milk secretion of 4 to 16-carbon FA could be limited by the mammary availability of 18-carbon FA for the initial acylation of glycerol in lipid-poor diets (<3%), while milk secretion of 18-carbon FA could in turn be limited by a lack of 4 to 16-carbon FA for complete glycerol esterification when high fat diets (3% to 6%) are fed. The reduction of short and medium chain FA is related to a lower *de novo* synthesis in the mammary gland, which may be due to two reasons: 1) decreased rumen production of volatile FA, which are their substrate in diets with added fat; 2) negative metabolic effect of long chain FA, or conjugated linoleic acid isomers on mammary enzymes (Chilliard and Ferlay, 2004). Sanz Sampelayo *et al.* (2007) pointed out that the higher rate of rumen transit in ewes and goats could turn down the negative effect of non-protected fat sources on rumen digestion of fibrous carbohydrates and the consequent decrease of precursors for the *de novo* synthesis in the udder. According to Chilliard *et al.* (2003) the high rumen transit rate could reduce the effect of dietary unsaturated FA on rumen production of conjugated linoleic acid isomers, which negatively affect mammary lipogenesis.

Effect of dietary lipids on milk protein

Tables 1, 2, and 3 show that dietary fat supplementation in cows and ewes decreases milk protein content compared to diets without added fat. Results of reports presented in table 4 show that this effect does not happen in goats consuming diets with added fat from different sources.

In cows, the negative effect is greater after the peak of lactation; its size is not related to a particular fat source, and increases with the degree of unsaturation (Wu and Huber, 1994; Schroeder *et al.*, 2004). The decrease of protein content can be explained by a reduction of milk casein content when added-fat diets are given. DePeters *et al.* (1987) observed that the addition of 3.5% and 7% extra fat to the diet reduced protein and casein content in a similar magnitude in both treatments when compared to the control diet (1.2 g protein and 0.9 g casein/kg of milk) while the percentage of casein in total nitrogen was only significantly reduced with the 7% fat added diet (74.53% *vs* 75.47% in control diet). Doreau and Chilliard (1992) calculated that the addition of fat to dairy cow diets reduces milk protein, casein, and casein/protein ratio by 1.6 g/kg, 1.5 g/kg, and 0.8%, respectively, while whey proteins and non-protein nitrogen are barely affected (±0.8 g/kg and ±0.2 g/kg, respectively).

In ewes, Osuna *et al.* (1998) observed that the addition of 4.5% extra fat to the diet as calcium salts of palm oil FA or its combination with oilseeds had little effect on milk protein content but reduced the proportion of casein in total protein. Zhang *et al.* (2006) obtained milk with less total protein and casein (46.5 g/kg and 35.4 g/kg) when ewes were fed sunflower seeds compared to a control diet (47.6 g/kg and 36.7 g/kg) or a diet supplemented with linseed (47.1 g/kg and 36.1 g/kg). In this paper, the percentage of casein in milk for the sunflower seed diet was 1.3% lower than for the control diet. On the other hand, Gargouri *et al.* (2006) found a negative linear regression between milk protein content and consumption of calcium salts of palm oil FA: protein content (g/L) = -0.0210 x calcium salts intake (g/d).

In goats, works by Teh *et al.* (1994), Mir *et al.* (1999), Brown-Crowder *et al.* (2001), Bernard *et al.* (2005), Schmidely *et al.* (2005), Maia *et al.* (2006a), and Fernandes *et al.* (2008) show that the content and production of milk protein are not negatively affected by the type of fat, unsaturation degree or level of inclusion into the diet. Regarding milk protein components, Sanz Sampelayo *et al.* (2002) observed that feeding a concentrate with 12% of calcium salts rich in polyunsaturated FA increased the percentage of serum albumin in whey proteins by 76% and reduced α-casein in total caseins by 22% without affecting the contents of total whey protein and total casein. This is most likely because there were non significant changes in the rest of the fractions for both groups of milk proteins.

Several hypotheses have been advanced to explain the observed reduction in milk protein content when fat sources are included in the diet of cows and ewes (Doreau and Chilliard, 1992). After reviewing the available literature, Wu and Huber (1994) pointed out that the decrease in protein content could be partially due to a dilution effect of the increased amount of milk produced because of the extra fat, as well as a shortage of available amino acids for the synthesis of protein to maintain pace with the increased milk production. In this sense, replacing dietary rumen digestible carbohydrates by lipids can bring a reduction of rumen microbial protein production (Coppock and Wilks, 1991), or it can increase the utilization of amino acids for gluconeogenesis due to a lower production and availability of propionate (Lobley, 1992). Other authors have suggested that the cause may be a low secretion of somatostatin (Casper and Schingoethe, 1989) or insulin (Mackle *et al.*, 2000), which would result in a low mammary amino acid uptake. The causes of the differences between cows and ewes and goats have not been documented, and could be due to unknown physiological and metabolic factors (Chilliard *et al.*, 2003).

In conclusion, the addition of extra fat to diets for cows may have counterproductive effects on milk production and composition when non-protected fat sources rich in unsaturated FA are used. Milk production and milk fat content are not negatively affected in goats and ewes by the consumption of diets with added fat, but milk protein content decreases in ewes. More research is clearly needed to identify the possible reasons for the different responses observed in cows, ewes, and goats.

References

Ashes JR, Gulati SK, Scott TW. Potential to alter the content and composition of milk fat through nutrition. J Dairy Sci 1997; 80:2204-2212.

Beauchemin KA, McGinn SM, Benchaar C, Holtshausen L. Crushed sunflower, flax, or canola seeds in lactating dairy cow diets: effects on methane production, rumen fermentation, and milk production. J Dairy Sci 2009; 92:2118-2127.

Bernard L, Rouel J, Leroux C, Ferlay A, Faulconnier Y, Legrand P, Chilliard Y. Mammary lipid metabolism and milk fatty acid secretion in Alpine goats fed vegetable lipids. J Dairy Sci 2005; 88:1478-1489.

Bouattour MA, Casals R, Albanell E, Such X, Caja G. Feeding soybean oil to dairy goats increases conjugated linoleic acid in milk. J Dairy Sci 2008; 91:2399-2407.

Bremmer DR, Ruppert LD, Clark JH, Drackley JK. Effects of chain length and unsaturation of fatty acid mixtures infused into the abomasum of lactating dairy cows. J Dairy Sci 1998; 81:176-188.

Brown-Crowder IE, Hart SP, Cameron M, Sahlu T, Goetsch AL. Effects of dietary tallow level on performance of Alpine does in early lactation. Small Rumin Res 2001; 39:233-241.

Casals RG, Caja G, Pol MV, Such X, Albanell E, Gargouri A, Casellas J. Response of lactating dairy ewes to various levels of dietary calcium soaps of fatty acids. Anim Feed Sci Technol 2006; 131:312-332.

Casper DP, Schingoethe DJ. Model to describe and alleviate milk protein depression in early lactation cows fed a high fat diet. J Dairy Sci 1989; 72:3327-3335.

Casper DP, Schingoethe DJ, Middaugh RP, Baer RJ. Lactational responses of dairy cows to diets containing regular and high oleic acid sunflower seeds. J Dairy Sci 1988; 71:1267-1274.

Chilliard Y, Doreau M, Gagliostro G, Elmeddah Y. Addition de lipides protégés (encapsulés ou savons de calcium) à la ration de vaches laitières. Effets sur les performances et la composition du lait. INRA Prod Anim 1993; 6:139-150.

Chilliard Y, Ferlay A. Dietary lipids and forages interactions on cow and goat milk fatty acid composition and sensory properties. Reprod Nutr Dev 2004; 44:467-492.

Chilliard Y, Ferlay A, Doreau M. Effect of different types of forages, animal fat or marine oils in cow's diet on milk fat secretion and composition, especially conjugated linoleic acid (CLA) and polyunsaturated fatty acids. Livest Prod Sci 2001; 70:31-48.

Chilliard Y, Ferlay A, Rouel J, Lamberet G. A review of nutritional and physiological factors affecting goat milk lipid synthesis and lipolysis. J Dairy Sci 2003; 86:1751-1770.

Chilliard Y, Ollier A. Alimentation lipidique et métabolisme du tissu adipeux chez les ruminants. Comparaison avec le porc et les rongeurs. INRA Prod Anim 1994; 7:293-308.

Cieslak A, Kowalczyk J, Czauderna M, Potkanski A, Szumacher-Strabel M. Enhancing unsaturated fatty acids in ewe's milk by feeding rapeseed or linseed oil. Czech J Anim Sci 2010; 55:496-504.

Coppock CE, Wilks DL. Supplemental fat in high-energy rations for lactating cows:effects on intake, digestion, milk yield, and composition. J Anim Sci. 1991; 69:3826-3837.

DePeters EJ, Taylor SJ, Finley CM, Famula TR. Dietary fat and nitrogen composition of milk from lactating cows. J Dairy Sci 1987; 70:1192-1201.

Dhiman TR, Satter LD, Pariza MW, Galli MP, Albright K, Tolosa MX. Conjugated linoleic acid (CLA) content of milk from cows offered diets rich in linoleic and linolenic acid. J Dairy Sci 2000; 83:1016-1027.

Doreau M, Chilliard Y. Influence d'une supplémentation de la ration en lipides sur la qualité du lait chez la vache. INRA Prod Anim 1992; 5:103-111.

Eugène M, Massé D, Chiquette J, Benchaar C. Meta-analysis on the effects of lipid supplementation on methane production in lactating dairy cows. Can J Anim Sci 2008; 88:331-334.

Fernandes MF, Ramos RC, Nunes de Medeiros A, Costa RG, Delmondes MA, Amorim A. Características físico-químicas e perfil lipídico do leite de cabras mestiças Moxotó alimentadas com dietas suplementadas com óleo de semente de algodão ou de girassol. R Bras Zootec 2008; 37:703-710.

Gargouri A, Caja G, Casals R, Mezghani I. Lactational evaluation of effects of calcium soap of fatty acids on dairy ewes. Small Rumin Res 2006; 66:1-10.

Glasser F, Doreau M, Ferlay A, Loor JJ, Chilliard Y. Milk fatty acids:mammary synthesis could limit transfer from duodenum in cows. Eur J Lipid Technol 2007; 109:817-827.

Gómez-Cortés P, Frutos P, Mantecón AR, Juárez M, de la Fuente MA, Hervás G. Milk production, conjugated linoleic acid content, and in vitro ruminal fermentation in response to high levels of soybean oil in dairy ewe diet. J Dairy Sci 2008a; 91:1560-1569.

Gómez-Cortés P, Frutos P, Mantecón AR, Juárez M, de la Fuente MA, Hervás G. Addition of olive oil to dairy ewe diets: effect on milk fatty acid profile and animal performance. J Dairy Sci 2008b; 91:3119-3127.

Gonthier C, Mustafa AF, Ouellet DR, Chouinard PY, Berthiaume R, Petit HV. Feeding micronized and extruded flaxseed to dairy cows: Effects on blood parameters and milk fatty acid composition. J Dairy Sci 2005; 88:748-756.

Harvatine KJ, Allen MS. The effect of production level on feed intake, milk yield, and endocrine responses to two fatty acid supplements in lactating cows. J Dairy Sci 2005; 88:4018-4027.

Hervás G, Luna P, Mantecón AR, Castañares N, de la Fuente MA, Juárez M, Frutos P. Effect of diet supplementation with sunflower oil in milk production, fatty acid profile and ruminal fermentation in lactating dairy ewes. J Dairy Res 2008; 75:399-405.

Litherland NB, Thire S, Beaulieu AD, Reynolds CK, Benson JA, Drackley JK. Dry matter intake is decreased more by abomasal infusion of unsaturated free fatty acids than by unsaturated triglycerides. J Dairy Sci 2005; 88:632-643.

Lobley GE. Control of the metabolic fate of amino acids in ruminants: a review. J Anim Sci 1992; 70:3264-3275.

Lock AL, Bauman DE. Modifying milk fat composition of dairy cows to enhance fatty acids beneficial to human health. Lipids 2004; 39:1197-1206.

Mackle TR, Dwyer DA, Ingvartsen KL, Chouinard PY, Ross DA, Bauman DE. Effects of insulin and postruminal supply of protein on use of amino acids by the mammary gland for milk protein synthesis. J Dairy Sci 2000; 83:93-105.

Maia FJ, Branco AF, Mouro GF, Coneglian SM, dos Santos GT, Minella TF, Guimarães KC. Inclusão de fontes de óleo na dieta de cabras em lactação: produção, composição e perfil dos ácidos graxos do leite. Rev Bras Zootec 2006a; 35:1504-1513.

Maia FJ, Branco AF, Mouro GF, Coneglian SM, Santos GT, Minella TF, Guimarães KC. Inclusão de fontes de óleo na dieta de cabras em lactação: digestibilidade dos nutrientes e parâmetros ruminais e sangüíneos. Rev Bras Zootec 2006b; 35:1496-1503.

Martin C, Rouel J, Jouany JP, Doreau M, Chilliard Y. Methane output and diet digestibility in response to feeding dairy cows crude linseed, extruded linseed, or linseed oil. J Anim Sci 2008; 86:2642-2650.

Mele M, Buccioni A, Petachi F, Serra A, Banni S, Antongiovanni M, Secchiari P. Effect of forage/concentrate ratio and soybean oil supplementation on milk yield, and composition from Sarda ewes. Anim Res 2006; 55:273-285.

Mele M, Serra A, Buccioni A, Conte G, Pollicardo A, Secchiari P. Effect of soybean oil supplementation on milk fatty acid composition from Saanen goats fed diets with different forage:concentrate ratios. Ital J Anim Sci 2008; 7:297-311.

Mierlita D, Daraban S, Lup F, Maerescu C. The influence of by-pass fats used in ewes diet on the productive performances and on the fatty acids profile from milk. Lucrări Ştiinţifice Seria Agronomie 2010; 53:200-204.

Mir Z, Goonewardene LA, Okine E, Jaegar S, Scheer HD. Effect of feeding canola oil on constituents, conjugated linoleic acid (CLA) and long chain fatty acids in goats milk. Small Rumin Res 1999; 33:137-143.

Murphy M, Uden P, Palmquist DL, Wiktorsson H. Rumen and total diet digestibilities in lactating cows fed diets containing full-fat rapeseed. J Dairy Sci 1987; 70:1572-1582.

Ollier S, Leroux C, de la Foye A, Bernard L, Rouel J, Chilliard Y. Whole intact rapeseeds or sunflower oil in high-forage or high-concentrate diets affects milk yield, milk composition, and mammary gene expression profile in goats. J Dairy Sci 2009; 92:5544-5560.

Ortiz V, Gómez-Cabrera A, Mena Y. Utilización de la semilla de girasol (normal y alta en ácido oleico) en la alimentación de vacas. Invest Agr: Prod Sanid Anim 1998; 13:5-12.

Osuna DR, Casals R, Caja G, Peris S. Effects of feeding whole oilseeds to partially replace calcium soaps of fatty acids on dairy ewes intake and milk production and composition. J Dairy Sci 1998; 81 Suppl. 1:302.

Pantoja J, Firkins JL, Eastridge ML, Hull BL. Effects of fat saturation and source of fiber on site of nutrient digestion and milk production by lactating dairy cows. J Dairy Sci 1994; 77:2341-2356.

Pérez-Alba LM, De Souza Cavalcanti S, Pérez Hernández M, Martínez Marín A, Fernández Marín G. Calcium soaps of olive fatty acids in the diets of Manchega dairy ewes:effects on digestibility and production. J Dairy Sci 1997; 80:3316-3324.

Rapetti L, Crovetto GM, Galassi G, Sandrucci A, Succi G, Tamburini A, Battelli G. Effect of maize, rumen-protected fat and whey permeate on energy utilisation and milk fat composition in lactating goats. Ital J Anim Sci 2002; 1:43-53.

Reynolds CK, Cannon VL, Loerch SC. Effects of forage source and supplementation with soybean and marine algal oil on milk fatty acid composition of ewes. Anim Feed Sci Technol 2006; 131:333-357.

Rotunno T, Sevi A, Di Caterina R, Muscio A. Effects of graded levels of dietary rumen-protected fat on milk characteristics of Comisana ewes. Small Rumin Res 1998; 30:137-145.

Sanz Sampelayo MR, Chilliard Y, Schmidely P, Boza J. Influence of type of diet on the fat constituents of goat and sheep milk. Small Rumin Res 2007; 68:42-63.

Sanz Sampelayo MR, Pérez L, Martín JJ, Amigo L, Boza J. Effects of concentrates with different contents of protected fat rich in PUFAs on the performance of lactacting Granadina goats Part II. Milk production and composition. Small Rumin Res 2002; 43:141-148.

Sauvant D, Bas P. La digestion des lipides chez le ruminant. INRA Prod Anim 2001; 14:303-310.

Schmidely P, Morand-Fehr P, Sauvant D. Influence of extruded soybeans with or without bicarbonate on milk performance and fatty acid composition of goat milk. J Dairy Sci 2005; 88:757-765.

Schroeder GF, Gagliostro GA, Bargo F, Delahoy JE, Muller LD. Effects of fat supplementation on milk production and composition by dairy cows on pasture: a review. Livest Prod Sci 2004; 86:1-18.

Silva MMC, Rodrigues MT, Branco RH, Rodrigues CAF, Sarmento JLR, Queiroz AC, Silva SP. Suplementação de lipídios em dietas para cabras em lactação: consumo e eficiência de utilização de nutrientes. R Bras Zootec 2007; 36:257-267.

Smith WA, Harris B. The influence of forage type on the production response of lactating dairy cows supplemented with different types of dietary fat. 3rd Florida Ruminant Nutrition Symposium 1992; [Access date: January 23, 2011] URL: http://dairy.ifas.ufl.edu/rns/1992/Smith.pdf.

Teh TH, Trung LT, Jia ZH, Gipson TA, Ogden KB, Sweeney TF. Varying amounts of rumen-inert fat for high producing goats in early lactation. J Dairy Sci 1994; 77:253-258.

Wu Z, Huber JT. Relationship between dietary fat supplementation and milk protein concentration in lactating cows: a review. Livest Prod Sci 1994; 39:141-155.

Zhang RH, Mustafa AF, Zhao X. Effects of feeding oilseeds rich in linoleic and linolenic fatty acids to lactating ewes on cheese yield and on fatty acid composition of milk and cheese. Anim Feed Sci Technol 2006; 127:220-23.