Animal Feed Science and Technology 198 (2014) 67–82

Contents lists available at ScienceDirect

Animal Feed Science and Technology

journal homepage: www.elsevier.com/locate/anifeedsci

Interaction between fish oil and plant oils or starchy concentrates in the diet: Effects on dairy performance and milk fatty acid composition in goats

P.G. Toral [a,b], J. Rouel [a,b], L. Bernard [a,b,*], Y. Chilliard [a,b,*]

[a] INRA, UMR1213 Herbivores, Site de Theix, F-63122 Saint-Genès-Champanelle, France
[b] Clermont Université, VetAgro Sup, BP 10448, F-63000 Clermont-Ferrand, France

ARTICLE INFO

Article history:
Received 20 December 2013
Received in revised form
15 September 2014
Accepted 22 September 2014

Keywords:
Goat
Fish oil
Linseed oil
Sunflower-seed oil
Milk fatty acid
Starch concentrate

ABSTRACT

Two experiments were performed to investigate the effects of supplementing a diet with fish oil either alone or with plant oils on dairy goat performance and milk fatty acid (FA) profile (Experiment 1), and the interaction between fish oil with the type and level of starch concentrate (Experiment 2). In Experiment 1, 84 goats were allocated to 7 experimental diets without a lipid supplement or with a low or high dose of fish oil (20 or 40 g/d, respectively) either alone or with linseed or sunflower-seed oils (the combinations included 130 g/d of oil supplements). In Experiment 2, 72 goats were allocated to 6 experimental diets without a lipid supplement and with a concentrate rich in corn and barley grain starch or with the high dose of fish oil (40 g/d) and concentrates rich in starch from barley grain, corn grain or both; or that were low in starch from barley grain or corn grain. In contrast to cows, in goats, fish oil supplements modulated milk FA composition without decreasing the milk fat content; this result may have been related to specific milk FA responses, such as a lack of or a small reduction in 18:0 and *c*9-18:1 (Experiment 1) or a moderate reduction compensated through increases in short-chain FA (Experiment 2) and limited increases in *t*10-18:1. The combinations of fish oil with sunflower-seed oil were more efficient than either fish oil plus linseed oil or fish oil alone at increasing ($P<0.05$) milk *c*9,*t*11-18:2 and *t*11-18:1 concentrations (up to 24- and 35-fold increases, respectively), simultaneously decreasing ($P<0.05$) medium-chain saturated FA (on average, 40% decrease). Based on the milk FA changes (*e.g.*, 18:2n-6, 18:3n-3, *t*11-18:1 and 18:0) in Experiment 2, diets rich in barley grain starch with fish oil would induce less extensive ruminal dietary FA biohydrogenation and better inhibit the *trans* 18:1 reduction than diets that are supplemented with the same level of fish oil but are low in barley grain starch or rich in corn grain starch. The apparent transfer rates of 20:5n-3 and 22:6n-3 from fish oil to milk were low (on average, 2.8% and 2.4%, respectively; Experiment 1) but were slightly higher in barley-grain treatments (on average, 5.1% and 7.6%, respectively) compared with corn-grain-only treatments (on average, 2.5% and 3.7%, respectively; Experiment 2). The milk *t*10-18:1 concentration remained low ($\leq$1.1% total FA) and the *t*10-18:1/*t*11-18:1 ratio was much lower than in cows fed fish oil with plant oils.

Abbreviations: CLA, conjugated linoleic acid; FA, fatty acid; FAME, fatty acid methyl ester; PC, principal component; PCA, principal component analysis.

* Corresponding authors at: INRA, UMR1213 Herbivores, Site de Theix, F-63122 Saint-Genès-Champanelle, France. Tel.: +33 473 62 41 14/40 51; fax: +33 473 62 45 19.
E-mail addresses: laurence.bernard@clermont.inra.fr (L. Bernard), yves.chilliard@clermont.inra.fr (Y. Chilliard).

http://dx.doi.org/10.1016/j.anifeedsci.2014.09.019
0377-8401/

1. Introduction

The potential benefits to human health have generated great interest in developing nutritional strategies that enhance the concentration of bioactive fatty acids (FA) in ruminant milk (Lock and Bauman, 2004; Chilliard et al., 2007). Diet supplementation with plant oils has been reported to be a good strategy for increasing milk *c*9,*t*11-conjugated linoleic acid (CLA) levels in goats (Mele et al., 2008; Bernard et al., 2009; Martínez Marín et al., 2011). Additionally, multiple studies have attempted to increase the concentration of 20:5n-3 and 22:6n-3 in ruminant milk by adding fish oil to the diet, but the apparent transfer rate of these FA from diet to milk is relatively low (Kitessa et al., 2001; Loor et al., 2005a; Toral et al., 2010a). However, as a rumen biohydrogenation modulator, fish oil yields large increases in milk *c*9,*t*11-CLA and *t*11-18:1 concentrations, particularly when combined with plant oils either in goats, cows, or sheep (Gagliostro et al., 2006; Shingfield et al., 2006; Toral et al., 2010a).

By contrast, the effect of fish oil supplementation on dairy performance largely depends on the ruminant species. In cows and ewes fed fish oil, lower milk fat content and yield are frequently observed (Chilliard et al., 2001; Loor et al., 2005a; Shingfield et al., 2006; Toral et al., 2010a). Goats are less prone to milk fat depression (Chilliard et al., 2003; Shingfield et al., 2010), but the data on fish oil supplementation in this species are too limited to offer a full picture (Kitessa et al., 2001; Gagliostro et al., 2006; Sanz Sampelayo et al., 2007; Bernard et al., 2010).

Furthermore, the response to lipid supplements is strongly influenced by the basal diet composition, and in cows and goats fed oils, enhanced dietary starch levels shift the ruminal biohydrogenation toward the *t*10-pathway at the expense of the *t*11-pathway (Shingfield et al., 2005; Mele et al., 2008; Bernard et al., 2009), which could detrimentally affect animal performance and the nutritional quality of ruminant-derived products (Roy et al., 2007; Shingfield et al., 2008). However, despite the volume of research on the effects of dietary concentrate levels on the milk FA profile (Chilliard et al., 2007), surprisingly few data describe the extent to which starch concentrates with different degradability affect milk FA composition (Jurjanz et al., 2004; Cabrita et al., 2009; Bernard et al., 2012). Interestingly, replacing corn grain with wheat grain as a dietary starch source influenced the goat response to sunflower-seed oil through decreasing the level of *c*9,*t*11-CLA and *t*11-18:1 as well as increasing the *t*10-18:1 and *de novo* synthesized FA in milk (Bernard et al., 2012). However, the effect from the interaction between fish oil and dietary starch sources on milk FA composition remains unknown.

Thus, this study included two experiments to investigate the effects of supplementing a diet with two doses of fish oil either alone or with plant oils (linseed or sunflower-seed oil) on dairy goat performance and milk FA profile (Experiment 1) as well as the interaction between fish oil and the type and level of starch concentrate (corn and barley grains; Experiment 2), with the objective of establishing the framework necessary to better control the FA profile and the levels of bioactive FA in goat milk without impairing animal performance, in particular milk fat content and yield. In contrast to cows, plant oil supplements increase milk fat yield in goats (Chilliard et al., 2003, 2007); however, it is unknown whether fish oil supplements can reverse the effects of plant oils. In cows fed fish oil, supplementation with sunflower-seed oil has been associated with greater milk CLA concentrations compared with linseed oil (AbuGhazaleh et al., 2003); however, information is currently unavailable for goats fed fish oil with plant oils. By contrast, corn and barley grains are sources of slowly and rapidly degradable starch in the rumen of goats, respectively (Archimède et al., 1996), and have been selected to determine whether the differences in the nature of starch affect the dairy goat response to fish oil supplements.

2. Material and methods

2.1. Animals, experimental diets and management

The experimental procedures were approved by the Animal Care Committee of INRA in accordance with the "Use of Vertebrates for Scientific Purposes Act" of 1985. In both experiments, the goats were housed in the INRA herd at Lusignan (France) in a barn with paddocks that included 12 animals and straw bedding. The animals were allocated to treatment groups based on milk yield, milk fat and protein content, parity, and lactation stage.

For Experiment 1, 84 Alpine goats with a mean parity of 2.4 ± 1.3 (28 primiparous and 56 multiparous) and 88 ± 15.4 days in milk at the beginning of the experiment were used. The goats were randomly allocated to 7 experimental diets (12 animals/diet) based on alfalfa hay and concentrate without a lipid supplement (control diet) or with a low dose of fish oil (20 g/d; LFO diet), a low dose of fish oil (20 g/d) with linseed oil (110 g/d; LFLO diet), a low dose of fish oil (20 g/d) with sunflower-seed oil (110 g/d; LFSO diet), a high dose of fish oil (40 g/d; HFO diet), a high dose of fish oil (40 g/d) with linseed oil (90 g/d; HFLO diet), or a high dose of fish oil (40 g/d) with sunflower-seed oil (90 g/d; HFSO diet). The ingredient details of the diets are provided in Table 1. Before the experiment began, the goats were fed the Control diet for a 3-week adaptation period.

For Experiment 2, 72 multiparous Alpine goats with a mean parity of 3.1 ± 1.1 and 112 ± 12.3 days in milk at the beginning of the experiment were used. The goats were randomly allocated to 6 experimental treatments (12 animals/treatment) based on alfalfa hay and a concentrate without a lipid supplement that was rich in corn and barley grain starch (Control diet) or concentrates with a high dose of fish oil (40 g/d) that were rich in corn and barley grain starch (CBFO diet), rich in corn grain starch (HCFO diet), rich in barley grain starch (HBFO diet), low in corn grain starch (LCFO diet) or low in barley grain starch (LBFO diet). The ingredient details of the diets are provided in Table 2. Before the experiment began, the goats were fed a diet