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Effects of extruded linseed and level and type of starchy concentrate in a diet containing fish oil on dairy goat performance and milk fatty acid composition

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ABSTRACT

Based on the potential benefits for long-term human health, nutritional strategies have been developed in order to increase the milk fat concentrations of bioactive fatty acids (FA) in ruminants. Dietary supplements of fish oil (FO), extruded linseed (EL) or a mixture of EL and FO increase *c*9,*t*11-CLA and n-3 PUFA in milk from bovine and caprine. These supplements associated with a high level of starch from concentrates cause milk fat depression in cows, but information for dairy goats is limited. An experiment was performed to investigate the effects of addition of extruded linseed to a diet containing fish oil in interaction with the type and level of starch concentrate on dairy goat performance and milk fatty acid (FA) profile. Following a 2 × 3 factorial design, 72 goats were allocated to 6 experimental diets based on alfalfa hay and with concentrates including fish oil (40 g/d) without or with extruded linseed (360 g/d) and either rich in starch from barley grain or extruded wheat or that were low in starch from barley grain. In contrast to cows, in goats adding extruded linseed to low-or high-starch diets based on hay and containing fish oil increases milk fat content and changes the milk FA composition in particular by increasing some bioactive FA with 18 carbons. In these conditions FA changes were characterized by decreases in SFA (on average 22% decrease) and increases in 18:0, *c*9-18:1, *t*11-18:1, *c*9,*t*11-CLA and 18:3n-3. The milk *t*10-18:1 concentration remained low (<1% total FA) and the *t*11-18:1/*t*10-18:1 ratio was much higher than in cows fed fish oil with plant oils. The combination of EL and FO induced larger concentrations in *t*11-18:1 and *c*9,*t*11-CLA than FO alone (2.9- and 2.1-fold higher, respectively). The apparent transfer rates of 20:5n-3 and 22:6n-3 from fish oil to milk were lower when EL was added to the diet (on average, 6.6 and 5.4%) compared to FO alone (on average, 8.0 and 7.4%, respectively). Extruded wheat, as the more rapidly degradable starch source in the rumen, decreased milk fat content. Based on the milk FA changes (e.g., *c*9,*t*11-CLA,18:2n-6, 18:3n-3, 20:5n-3, 22:6n-3), diets rich in starch from barley grain would induce a lower rumen bacterial biomass and a more extensive biohydrogenation of dietary FA in the rumen than diets rich in starch from extruded wheat. Starch level in the diets had negative effect on milk yield but moderate effects on milk fat and FA content, under these dietary conditions.

Abbreviations: CLA, conjugated linoleic acid; FA, fatty acid; FAME, fatty acid methyl ester.

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1. Introduction

Nutrition is the main factor that determines the secretion of specific fatty acids (FA) in ruminant milk, and nutritional strategies that enhance the concentration of bioactive FA (such as n-3 FA and conjugated FA) in milk have been investigated (Lock and Bauman, 2004; Chilliard et al., 2007). Indeed, addition of plant oils to diets has been reported to efficiently increase 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). In goat milk, as in cow, most of the *c*9,*t*11-CLA is formed from the desaturation of *t*11-18:1 (Bernard et al., 2010) and the nutritional strategies that enhance ruminal synthesis of *t*11-18:1 increase milk *c*9,*t*11-CLA concentration. Fish oil in combination with sunflower-seed or linseed oil is more effective than fish oil alone (Gagliostro et al., 2006; Toral et al., 2014) in increasing goat milk *t*11-18:1 and *c*9,*t*11-CLA concentrations. These effects are a consequence of higher ruminal *t*11-18:1 production due to the inhibition by very-long-chain FA from fish oil of the last biohydrogenation step of dietary PUFA to 18:0 (AbuGhazaleh et al., 2003). Besides an increase in milk *c*9,*t*11-CLA, addition of either fish oil or linseed (as oil or extruded seeds) alone in the diet of dairy goats results in increasing either 20:5n-3 and 22:6n-3 (Toral et al., 2014) or 18:3n-3 (Bernard et al., 2009, 2015) without decreasing milk fat yield, contrary to cows (Chilliard et al., 2003, 2007). However, the increase in goat milk content of omega-3 FA is limited due to their relatively low transfer rate from diet to milk (Kitessa et al., 2001; Toral et al., 2014).

High-starch diets with or without plant oil supplements change the levels of bioactive FA in goat milk without decreasing milk fat content and yield, in contrast to cows (Chilliard et al., 2007). These effects have been related to the ruminal biohydrogenation pathways which are more stable, leading to a lower formation of *t*10 containing intermediates in goats compared with cows, in particular *t*10,*c*12-CLA, which has been recognized for its antilipogenic effects (Shingfield et al., 2010). Recent studies demonstrated that the level and type of starch concentrate in the diet (corn or barley) has no effect on milk and milk components yield in goats fed fish oil (Toral et al., 2014). However, putative interactions between fish oil, oilseeds, and dietary starch sources on milk FA composition have not been studied yet.

Barley and extruded wheat grains are reported as rapidly degradable starch sources in the bovine (Sauvant et al., 1994) and caprine (Archimède et al., 1996), with wheat having a higher starch soluble fraction and degradation rate compared to barley (Herrera-Saldana et al., 1990); these differences are known to be accentuated by the extrusion treatment of wheat (Walhain et al., 1992). Thus, in the present study, these starch sources were chosen to determine whether the differences in the nature of starch and of its ruminal degradability affect the dairy goat response, in terms of animal performance and milk FA profile, to the inclusion of extruded linseed in a diet containing fish oil. Our objective was to increase the current knowledge on the nutritional strategies and interactions among dietary ingredients 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.

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. The goats were housed in the INRA herd at Lusignan (France) in a barn with paddocks that included 12 animals and straw bedding. Animals were allocated to treatment groups based on milk yield, milk fat and protein content, parity and lactation stage.

For the experiment, 72 Alpine goats of parity 3.1 ± 1.02 (all multiparous) and 89 ± 9.9 days in milk at the beginning of the experiment were used. Six experimental groups of goats were constituted and balanced according to milk production, milk fat and protein content and BW and, following a 2×3 factorial design, randomly allocated to 6 experimental treatments (12 animals/treatment) based on alfalfa hay and concentrates including fish oil (40 g/d): with or without extruded linseed (EL; 360 g/d) and three types or levels of starch, either high or low in starch from barley grains (respectively HB and LB diets), or high in starch from extruded wheat (HW diet). The ingredient details of the diets are provided in Table 1. Before the experiment began, the goats were fed a diet with an intermediate starch level from corn grain (149 g/kg DM) during a 3-week adaptation period without fish oil supplement; each group then received an experimental diet for a 4-week period.

Alfalfa hay was fed *ad libitum* and the quantity of concentrate distributed in each paddock including twelve animals was calculated based on the predicted forage consumption (INRA, 1989; Rouel et al., 1997) to cover 115% of the metabolizable energy requirements for maintenance and milk yield. The concentrates were offered in two equal meals at 09:30 and 14:30 h in each paddock and calculated to cover the metabolizable energy requirements for maintenance and milk yield; the animals were blocked into the feeding rack to support similar individual consumption; the forage: concentrate ratio was 58:42. Fish oil and/or extruded linseed were mixed manually with concentrate ingredients immediately before feeding, and clean water was always available. Hay and concentrate offered and refusals in each paddock were weighed daily over four consecutive days each week. The goats were milked daily at 08:00 and 16:30 h. The experiment was conducted during spring (from March through the middle of May).