Livestock Science 170 (2014) 53–62

Contents lists available at ScienceDirect

Livestock Science

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

Effect of flax meal on the production performance and oxidative status of dairy cows infused with flax oil in the abomasum

L.S. Lima [a], M.-F. Palin [b], G.T. Santos [a], C. Benchaar [b], L.C.R. Lima [a], P.Y. Chouinard [c], H.V. Petit [b,*]

[a] Departamento de Zootecnia, Universidade Estadual de Maringá, Maringá PR 87020-900, Brazil
[b] Dairy and Swine Research and Development Centre, Agriculture and Agri-Food Canada, Sherbrooke QC J1M 0C8, Canada
[c] Département des Sciences Animales, Université Laval, Québec, Québec G1V 0A6, Canada

ARTICLE INFO

Article history:
Received 21 May 2014
Received in revised form
23 September 2014
Accepted 26 September 2014

Keywords:
Abomasal infusion
Conjugated diene
Fat supplementation
Flaxseed
Linseed
Omega-3 fatty acids

ABSTRACT

Rumen bypass of flax oil (FO), which is rich in omega-3 fatty acids (FA), contributes to increase polyunsaturated FA proportion in milk fat. Flax meal (FM) is a source of antioxidants, which may reduce oxidative damage in cows given omega-3 FA. The aim of this study was to investigate the effects of dietary FM supplement on performance and antioxidant status in dairy cows infused with FO in the abomasum. Eight rumen fistulated lactating Holstein cows were assigned to a double 4×4 Latin square design with a 2×2 factorial arrangement of treatments: (1) control diet with no FM (CO); (2) diet containing 124 g/kg FM in the dry matter (DM); (3) CO and 250 g FO/d infused in the abomasum; and (4) FM and 250 g FO/d infused in the abomasum. Intake of DM and total DM input (including abomasally infused oil) were increased for cows fed FM and reduced for cows infused with FO. Milk production and milk composition did not differ among treatments except for lactose concentration that was increased with FO infusion. Milk fat from cows fed FM had lower omega-6 FA proportions. Abomasal infusion of FO increased proportions of polyunsaturated, omega-6 and omega-3 FA in milk fat. Cows fed CO with no FO infusion showed higher omega-6/omega-3 FA ratio in milk fat compared with the other treatments, whereas no difference was observed between CO and FM when FO was infused in the abomasum. Feeding FM did not change plasma and milk thiobarbituric acid reactive substances concentrations, whereas FO increased them. Infusion of FO in the abomasum increased the peroxidizability index, the maximal conjugated diene (CD) production and rate of CD production, whereas lag time and time to reach maximum amount of CD were reduced. Plasma antioxidant capacity before feeding was increased when cows received dietary FM or FO abomasal infusion, whereas no differences were observed 3 h postfeeding. Results suggest that FM supplementation to dairy cows receiving a source of polyunsaturated FA that bypasses the rumen does not provide any benefits for protecting cows and milk against lipoperoxidation.

1. Introduction

Consumption of omega-3 fatty acids (FA) has been associated with a decrease in risk factors of cancer (Simopoulos, 2002a) and coronary diseases (Simopoulos, 2002b). Previous studies have shown increased proportions

Abbreviations: DM, dry matter; CD, conjugated diene; CO, control diet; FA, fatty acids; FM, flax meal; FO, flax oil; CD_{max}, maximum CD production; MDA, malondialdehyde; V_{max}, rate of diene production; SCC, somatic cell counts; TBARS, thiobarbituric acid reactive substances; TAC, total antioxidant capacity; T_{max}, time to reach maximum amount of CD formed; VFA, volatile fatty acids

* Corresponding author. Tel.: +1 819 780 7210; fax: +1 819 564 5507.
E-mail address: helene.petit@agr.gc.ca (H.V. Petit).

http://dx.doi.org/10.1016/j.livsci.2014.09.023
1871-1413/

of polyunsaturated FA, including omega-3 FA, in milk fat of dairy cows infused with flax oil (FO) in the abomasum (Côrtes et al., 2011; Kazama et al., 2010). Although a higher proportion of polyunsaturated FA in milk fat is desirable for consumers due to potential health benefits, this also increases oxidation of milk fat (Shiota et al., 1999). Indeed, milk enriched in omega-3 FA may be more susceptible to oxidation with the development of rancid odors and flavors (Puppel et al., 2012; Timmons et al., 2001), thus decreasing the nutritional quality and shelf life of milk and dairy products. Additionally, feeding omega-3 rich diets to dairy cows may render tissues susceptible to free radical-mediated lipid peroxidation, which is further aggravated in high producing cows that are naturally prone to oxidative stress (Bernabucci et al., 2005; Castillo et al., 2005). However, studies have demonstrated that inclusion of antioxidants in the diet diminishes the negative effects of oxidized fat by scavenging peroxides and reducing peroxidation of FA (Frankel, 2005) and enhances lactation performance and antioxidant status of cows (Vazquez-Anon et al., 2008). For example, plant polyphenols associated with vitamin E decrease lipoperoxidation damage generated by the oxidative stress generated by diets containing FO (Gobert et al., 2009). Similarly, supplementation with the antioxidants ethoxyquin and tertiary butylhydroquinone improves the oxidative status of dairy cows fed rumen-inert FA (Wang et al., 2010).

Flax products are rich in plant lignans, which have strong antioxidant properties (Landete, 2012). Plant lignans are metabolized in the two main mammalian lignans enterodiol and enterolactone under the action of the rumen microbiota (Gagnon et al., 2009a). Feeding flax hulls to cows have increased concentration of enterolactone in urine, plasma and milk (Côrtes et al., 2013), and there was a linear increase in milk enterolactone concentration with the proportion of flax meal (FM) in the diet (Petit et al., 2009). Previous results have shown that antioxidant activity of plant and mammalian lignans is greater than that of vitamin E (Prasad, 2000). Rajesha et al. (2006) demonstrated in a rat model challenged with CCl_4 that flax seed supplementation restores the activity of hepatic enzymes such as superoxide dismutase, catalase, and glutathione peroxidase, which are involved in defense mechanisms against oxidative stress. Moreover, feeding flax hulls to dairy cows was found to increase catalase, glutathione peroxidase 1 and superoxide dismutase 1 mRNA levels in the mammary gland (Côrtes et al., 2012). A decrease in production of thiobarbituric acid reactive substances (TBARS) was also observed in the milk of cows receiving 50 and 100 g/kg FM in the diet, along with a linear reduction in rumen fluid TBARS production 2 h after feeding (Schogor et al., 2013). However, the potential benefits of FM to reduce the oxidative damage in a cow model infused with omega-3 FA have never been investigated. Therefore, we hypothesized that dietary FM reduces plasma and milk oxidative damage in dairy cows supplemented with omega-3 FA. Thus, the aim of the experiment was to investigate the effects of FM on performance and antioxidant status of dairy cows infused with FO in the abomasum.

2. Material and methods

2.1. Cows, diets, and experimental procedures

Eight multiparous lactating Holstein cows fitted with ruminal cannulas (10 cm, Bar Diamond Inc., Parma, ID, USA) were assigned to a replicated 4×4 Williams Latin square design with a 2×2 factorial arrangement of treatments and four 21 d periods balanced for residual effect. The experimental treatments were as follows: (1) control diet with no FM (CO); (2) diet containing 124 g/kg FM in the dry matter (DM); (3) CO and 250 g FO/d infused in the abomasum; and (4) FM and 250 g FO/d infused in the abomasum. Flax oil contained, on total FA basis, 65 g/kg of 16:0, 48 g/kg of 18:0, 258 g/kg of *cis*9-18:1, 169 g/kg of *cis*9,*cis*12-18:2, 447 g/kg of *cis*9,*cis*12,*cis*15-18:3 and 13 g/kg of others. Flax meal was incorporated in the total mixed diet and contained, on DM basis, 363 g/kg of crude protein, 256 g/kg of neutral-detergent fiber, 177 g/kg of acid-detergent fiber and 12.9 g/kg of ether extract.

Cows were weighed on the first and last day of each experimental period. Cows averaged 108 ± 39 days in milk, 32.6 ± 5.6 kg of milk/d, and 759 ± 44 kg of body weight at the beginning of the experiment. Cows were housed in individual stalls with free access to water and were fed twice a day (08:00 and 19:00 h) for ad libitum intake (100 g/kg of refusals as fed). The diets (Table 1) were formulated to meet requirements for cows producing 30 kg/d of milk with 35 g/kg of fat (National Research Council, 2001). The oil was stored at 4 °C and was mixed before infusion. Milking times were 06:30 and 19:30 h, and milk yield was recorded at each milking. Cows were cared for in accordance with the guidelines of the Canadian Council on Animal Care (1993) and all experimental procedures were approved by the Dairy and Swine Research and Development Centre Animal Care Committee.

To perform abomasal infusions, an infusion line was inserted through the ruminal cannula and the sulcus omasi as described by Gressley et al. (2006). Plastisol discs (12 cm in diameter and 9 mm in height) were used to anchor the infusion line, and placement of infusion lines was monitored daily to ensure postruminal delivery. Variable-speed peristaltic pumps (Masterflex L/S; Cole-Parmer Canada Inc., Montreal, QC, Canada) were used to deliver FO in the abomasum at a rate of 10.86 g/h. Cows were infused from days 8 to 21 with 100% of the experimental dose of oil over a 23-h period (from 13:00 to 12:00 h).

Feed intake was recorded daily and samples of total mixed diets and FM were taken daily from days 15 to 21 and pooled by cow within period. All samples were frozen at -20 °C for subsequent drying at 55 °C and ground through a 1 mm screen in a Wiley mill for further analyses.

On day 19, ruminal contents were collected 0, 2, 4, and 6 h after the morning meal from different locations within the rumen (the anterior dorsal, anterior ventral, medium ventral, posterior dorsal, and posterior ventral locations). The ruminal contents were homogenized and then strained through four layers of cheesecloth. Samples were taken at different times post-feeding to look at the evolution of parameters related to the oxidative status after feeding a