AS-1283

Using Flax in Livestock Diets

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Introduction

Flax (*Linum usitatissimum)* is an oilseed produced predominantly in the northern Great Plains and Canada (Berglund and Zollinger, 2002). Traditionally, flax is crushed to produce linseed oil for industrial applications, and the resultant flaxseed (also called linseed) meal is used as a protein supplement in livestock feeds.

Research indicates several possible human health benefits associated with consumption of flax (Conners, 2000). Flax contains approximately 20 percent alpha-linolenic acid (ALA; DM basis), an essential omega-3 fatty acid that is a precursor for eicosapentaenoic acid (EPA), which in turn is a precursor for the formation of eicosanoids. Eicosanoids are hormone-like compounds that play an essential role in immune response.

Additionally, some evidence suggests EPA can elongate further to docosahexanoic acid (DHA), an omega-3 fatty acid that is essential for cell membrane integrity, as well as brain and eye health (Conners, 2000). Flax also is the richest plant source of the lignan precursor secoisolariciresinol diglycoside (SDG), which the rumen microorganisms or the hind gut microorganisms in nonruminant animals convert to mammalian phytoestrogens (Thompson et al., 2004). Phytoestrogens are thought to have potential uses in hormone replacement therapies and cancer prevention (Harris and Haggerty, 1993).

Recent research indicates that products, such as eggs and beef, from animals fed flax have increased levels of omega-3 fatty acids (Scheideler et al., 1994; Maddock et al., 2003). This has led to a renewed interest in flax production and feeding flax to livestock. Therefore, information about the use of flax in livestock feeds is needed. This review provides information regarding the nutritive and feeding value of flax, examines the literature on the implications of using flax in livestock diets, and offers recommendations on future research needs.

Nutritive Value of Flax

Similar to most grains and oilseeds, the composition of flax can vary based on variety, environmental factors and method of analysis (Daun et al., 2003). Limited data are available regarding proximate (nutritive) analysis of flax. Values most commonly used are 41 percent oil, 20 percent protein and 28 percent dietary fiber (Canadian Grain Commission, 2001; DM basis). Reported protein

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FEBRUARY 2005

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values range from 18.8 percent to 24.4 percent (Daun and Pryzbylski, 2000). When compared to other oilseeds (Table 1), flax falls between soybeans and sunflowers (oil-type) in energy content and is similar to sunflowers, canola and cottonseeds for crude protein content. The amino acid composition of flax is similar to soybeans (Table 2).

Table 1. Nutrient content of selected oilseeds (DM basis)

	Flax[a]	Canola[a]	Soybeans[a]	Sunflowers[ac]	Cottonseed[b]
DM (%)	94	92	90	94	91
TDN (%)	110	115	91	121	95
NEm (Mcal/kg)	2.82	2.95	2.11	3.12	2.38
NEg (Mcal/kg)	1.96	2.00	1.47	2.40	1.67
CP (%)	22.8	21.0	41.7	17.9	23.0
Lipid (%) [d]	35.0	40.0	18.8	41.0	17.5
ADF (%)	8.0	12.0	10.0	39.0	40.0
Ca (%)	0.26	0.35	0.27	0.18	0.16
P (%)	0.56	0.68	0.63	0.56	0.62

[a]Adapted from Alternative Feeds for Ruminants, Lardy and Anderson, 1999 (except lipid).
[b]NRC, 1996.
[c]Sunflowers are oil type.
[d]Lipid percentages are adapted from McDonald, 1994 (except soybeans and cottonseed, which were adapted from NRC, 1996).

Fatty Acid Content

Flax is a rich source of the omega-3, polyunsaturated alpha-linolenic acid (ALA; Figure 1). This differs from other oilseeds, such as soybeans, cottonseed, corn and sunflowers, that are lower in omega-3 and higher in omega-6 polyunsaturated linoleic acids. Additionally, flax is lower in saturated fatty acids compared with soybeans, cottonseed and corn.

Vitamin and Mineral Content

Table 3 lists the vitamin content of flaxseed meal, soybean meal and sunflower meal. Flaxseed meal is lower in choline and higher in thiamin than soybean meal or sunflower meal. Flaxseed meal is similar to soybean meal in most other vitamins.

Table 4 lists the mineral content of flax, soybeans and cottonseed. Flax is similar to soybeans in mineral content, with the exception that flax is much lower in potassium. Flax also is higher in magnesium than either soybeans or cottonseed.

Table 2. Amino acid composition of select oilseeds

	Flax[a]	Soybeans[b]	Sunflowers[b]
	- - - - - - g/100 g protein - - - - - -		
Arginine	9.2	7.32	8.18
Cystine	1.1	1.5	1.77
Histidine	2.2	2.77	2.60
Isoleucine	4.0	4.56	4.09
Leucine	5.8	7.81	6.41
Lysine	4.0	6.29	3.56
Methionine	1.5	1.44	2.29
Phenylalanine	4.6	5.26	4.62
Threonine	3.6	3.96	3.72
Tryptophan	1.8	1.26	1.19
Valine	4.6	4.64	4.95

[a]Adapted from Oomah and Mazza, 1993.
[b]Adapted from NRC, 2001.

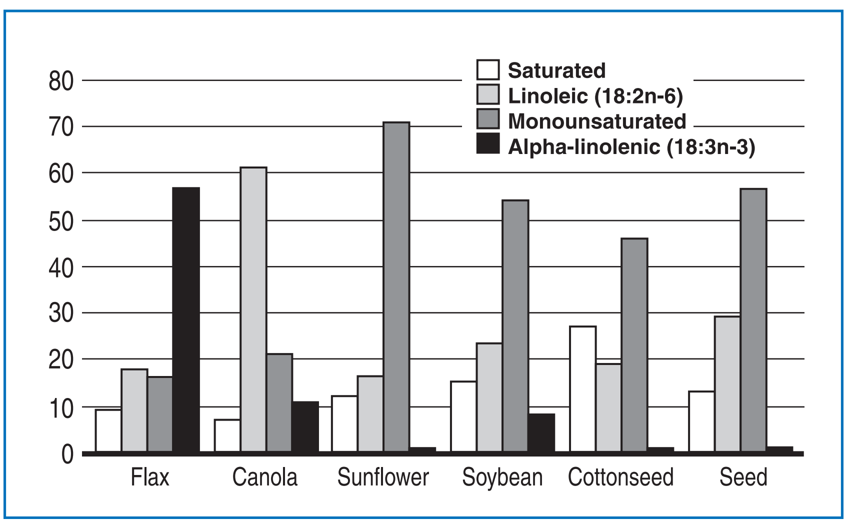

Figure 1. Fatty acid composition of flax and other common oilseeds (Adapted from Flax Council of Canada, 1997 and NRC, 1998, Nutrient Requirements of Swine, 10th revised ed.)

Table 3. Vitamin content of flaxseed meal, soybean meal and sunflower meal, mg/kg as fed[a]

	Flax	Soybeans	Sunflowers
Biotin	0.41	0.26	1.45
Choline	1512	2731	3150
Folacin	1.30	1.37	1.14
Niacin	33	22	220
Pantothenic Acid	14.7	15.0	24.0
Riboflavin	2.9	3.1	3.6
Thiamin	7.5	3.2	3.5
Vitamin B6	6.0	6.4	NG
Vitamin E	2.0	2.3	9.1
Beta Carotene	0.2	0.2	0.0

[a]Adapted from Nutrient Requirements of Swine (NRC, 1998).
NG = Not Given

Table 4. Mineral content of selected oilseeds (DM basis)

	Flax[a]	Cottonseed[b]	Soybeans[b]
Calcium, %	0.24	0.16	0.27
Magnesium, %	0.43	0.35	0.27
Phosphorus, %	0.62	0.62	0.65
Potassium, %	0.83	1.22	2.01
Copper, ppm	10	10	20
Iron, ppm	50	160	180
Manganese, ppm	30	10	40
Sodium, ppm	270	300	400
Zinc, ppm	40	40	60

[a]Adapted from the Flax Council of Canada, 1997
[b]NRC, 1996

Flax as a Feedstuff

Because flax is high in oil (35 percent; McDonald, 1994), it is considered a fat source in livestock rations. Fats traditionally have been used in livestock diets to increase energy density, reduce dust, eliminate fines and to aid in processing, such as pelleting (Byers and Schelling, 1988). Generally, fat is limited to 5 percent of DM in ruminant diets, as fats can interfere with rumen fermentation (Byers and Schelling, 1988). Using this rule, flax may be added at 12 percent to 14 percent (DM basis) to ruminant diets.

This appears to hold true when using flax in beef cattle diets, as Drouillard et al. (2004) offered beef steers 0 percent, 5 percent, 10 percent and 15 percent flax and noted a linear decrease in DM intake as flax levels increased. Additionally, because of its relatively high protein content (22.8 percent; Lardy and Anderson, 1999), flax might be considered a source of supplemental protein; however, considerations for oil content may limit the amount of protein flax might add in a ruminant diet.

Cattle

Feedlot Performance

Several recent studies have included flax in beef feedlot rations with mixed results. Drouillard et al. (2002) fed flax at 0 percent, 5 percent, 10 percent and 15 percent of diet DM and found that when fed at 5 percent of DM, flax increased DM intake but did not affect gain or gain efficiency. Additionally, Drouillard et al. (2002) investigated the timing of flax inclusion by feeding flax at 0 percent (diet DM) for 109 days, 5 percent for 109 days, 5 percent for the first 60 days and 0 percent for the last 49 days, or 0 percent for the first 60 days and 5 percent for the last 49 days. All treatments had similar gain (3.75 ± 0.64 lb/day), DM intake (19.6 ± 2.7 lb/day), and gain efficiency (0.19 ± 0.01 gain:feed).

Maddock et al. (2004) fed whole or processed (rolled or ground) flax, included at 8 percent of diet DM, and reported significant increases in gain and gain efficiency and no differences in DM intake (Table 5), when compared with a corn-based control diet. Additionally, data from this study suggests that processing flax is necessary to optimize gain and nutrient utilization. When flax was rolled or ground, gain and gain efficiency increased, compared with feeding whole flax.

Milk Production

Goodridge et al. (2001) fed lactating dairy cows casein-protected flax at either 1.76 lb or 3.53 lb/lb milk fat produced and Ward et al. (2002) fed lactating dairy cows either solin (or linola, a cultivar of flax), flax and canola at 8 percent of diet DM. No differences in milk production were found in either trial. Kennelly and Khoransani (1994) fed four levels of flax (0 percent, 5 percent, 10 percent and 15 percent diet DM) and noted no differences in intake or milk yield.

Goodrich et al. (2001) reported that flax-fed cows produced milk higher in protein, compared with cows fed casein-protected linola, a variety of solin that is high in linoleic acid (18:2). Ward et al. (2002) compared flax to solin, canola and control (barley- and silage-based) diets and reported that cattle fed flax diets had lower milk protein yields (expressed as either lb/d or percent) than cows fed the control diet. Kennelly and Khoransani (1994) also reported that as dietary flax levels increased, milk protein decreased.

Feeding flax can alter milk fatty acid profiles. Kennelly and Khoransani (1994) fed 0 percent, 5 percent, 10 percent or 15 percent (DM) whole-flax seed to mid-lactation Holstein cows and reported linear increases in milk long-chain fatty acids and polyunsaturated fatty acids, including ALA, as flax level increased. Additionally, Goodridge et al. (2001) reported that milk levels of ALA increased linearly with increasing dietary flax inclusion. Petit et al. (2001) included 17 percent formaldehyde-protected whole flax to lactating dairy cows and increased milk ALA levels, compared with other fat sources. Ward et al. (2002) fed 8 percent canola, solin or flax to dairy cows and reported increases in milk ALA content for those cows fed the flax diet.

Health

Numerous reports indicate how flax and/or its components (specifically ALA and SDG) are beneficial to human health, including reducing the risk of heart disease and stroke, modulating autoimmune disorders such as lupus and nephropathy, and decreasing incidences of certain cancers (Conners, 2000; Thompson et al., 2004). Research on animal health generally has been limited to beef feedlot cattle and to a limited degree in dairy cattle.

Drouillard et al. (2002) conducted two experiments with newly weaned calves to evaluate the effect of flax inclusion in receiving rations on morbidity. In experiment 1, 370 steer calves were fed 0 percent, 5 percent, 10 percent, 15 percent or 20 percent flax or 4 percent tallow for 36 to 40 days and no differences were observed for cases of bovine respiratory disease (BRD). In experiment 2, weaned heifer calves were fed no flax, 4 percent tallow, 10 percent flax, 4 percent flax oil or linseed meal with 4 percent tallow for 40 or 41 days. Incidences of BRD were highest in heifers fed the control diets. Compared with tallow, flax and flax oil treatments had fewer heifers retreated for BRD.

Farren et al. (2002) fed 4 percent tallow, 12.9 percent flax and an algae source of DHA to evaluate effects on immune response. Diets were fed to feedlot steers for 14 days prior to an injection of lipopolysaccharide (LPS) endotoxin as an immune challenge. Flax-fed steers had lower rectal temperatures three to six hours after LPS injection, compared with tallow- and algae-fed steers, and flax-fed steers had higher blood levels of haptoglobin, a positive indicator of immune response, compared with tallow-fed steers.

Table 5. Effects of processing flax on feedlot performance

	Diets[a]					P-values[b]			
Item	Control	Whole	Rolled	Ground	SE	Treatment	Control vs. Flax	Whole vs. Processed	Rolled vs. Ground
DMI, lb/d	25.6	25.0	25.1	25.1	0.4	0.79	0.34	0.90	0.96
ADG, lb/d	3.08	3.18	3.42	3.41	0.08	0.01	0.008	0.01	0.64
Gain:Feed	0.12	0.13	0.14	0.14	0.01	<0.001	0.001	0.008	0.68

[a]Control treatment was a basal, no-flax diet; whole, rolled and ground treatments included flax in the diet at 8 percent of DM.

[b]P-values are associated with F-test for treatment and contrasts of control diets vs. diets that include flax, whole-flax diet vs. treatments where flax was processed, and the rolled-flax diet vs. the ground-flax diet.

Reproduction

Petit et al. (2001) reported increased first-service conception rates (87.5 percent vs 50.0 percent) in dairy cows fed 17 percent flax, compared with dairy cows fed other sources of fat. The authors attributed this response to increased energy balance for the cows fed the flax diet.

Carcass, Muscle Composition and Meat Quality Factors

Because flax is high in fat, considerable interest has been expressed in using flax to enhance USDA quality grade. Research in this area has provided mixed results. Maddock et al. (2003) included 3 percent or 6 percent ground flax in finishing diets for feedlot steers fed for 56 days prior to harvest. No differences were noted for carcass characteristics, including 12th-rib fat thickness, rib-eye area or USDA yield and quality grades. In a second experiment, Maddock et al. (2004) included flax at 8 percent of DM in diets for feedlot heifers and determined there was a tendency ($P = 0.14$) for flax to increase marbling scores.

Drouillard et al. (2002) received weaned calves for 36 to 40 days on diets that contained tallow and either 0 percent, 5 percent, 10 percent, 15 percent or 20 percent flax, then finished calves from the tallow and 10 percent flax diets on a common finishing diet, and reported that those cattle fed 10 percent flax had higher marbling scores than the steers offered tallow (Sl^{60} vs Sm^{00}, respectively.) Additionally, Drouillard et al. (2004) fed Holstein steers 0 percent or 5 percent flax for either 109 or 157 days and reported that flax addition increased the percentage of steers that graded USDA choice.

Whether using flax will affect cutability and yield of beef carcasses is unclear at this point. Drouillard et al. (2004) fed increasing levels (0 percent, 5 percent, 10 percent or 15 percent flax) to beef steers and noted a quadratic response to flax for USDA yield grade. Flax added at 5 percent or 10 percent of DM had greater USDA yield grades than those steers fed 0 percent or 15 percent. These results are similar to those reported by Maddock et al (2004) in which flax included at 8 percent of diet DM increased USDA yield grade. Conversely, Drouillard et al. (2004) reported that feeding 5 percent flax to Holstein steers did not affect USDA yield grades.

Due to an increase in consumer interest surrounding dietary omega-3 fatty acids, researchers have hypothesized that flax inclusion in feedlot diets will alter end-product fatty-acid profiles positively and research has proven that this occurs. Muscle from steers fed diets that included flax had higher ALA content (47 g/kg lipid), compared with those steers fed either basal corn (34 g/kg lipid) or barley (39 g/kg lipid) diets (Maddock et al., 2003). Steers fed 5 percent flax had higher muscle levels of ALA than steers fed no flax (Drouillard et al., 2002), and Drouillard et al. (2004) reported increased ALA content in both muscle and fat samples collected from Holstein steers fed 5 percent flax for either 109 or 157 days, compared with control steers.

Maddock et al. (unpublished data) found increases in both phospholipid and neutral lipid ALA fractions from cattle offered 8 percent flax vs. a corn/linseed meal control diet, and also noted feeding 8 percent flax increased phospholipid longer-chain omega-3 fatty acids, such as EPA, docosopentanoic acid (DPA; 22:5n-3) and DHA. Drouillard et al. (2000; 2004) also reported increases in EPA and DHA in beef from cattle offered 5 percent or greater flax.

Due to increases in unsaturated fatty acids in flax-fed beef, Drouillard et al. (2004) looked at the use of vitamin E in flax-supplemented beef feedlot diets and reported beef from cattle supplemented with vitamin E had brighter retail shelf color scores than those not offered flax, but that consumers did not consider either treatment group to be unacceptable. Drouillard et al. (2004) also noted that no differences occurred in lipid oxidation of fatty acids in beef from flax-fed cattle and cattle fed control diets.

Literature on how feeding flax to cattle affects palatability of the resultant meat product also is unclear. Sensory panel results (Maddock et al., 2003; 2004) suggested that flax-fed steers produced strip steaks that were less juicy, compared with steers fed basal corn diets. In contrast, Drouillard et al. (2004) reported no differences in sensory panel observations for juiciness, tenderness or flavor.

Maddock et al. (2004) also found that feeding 8 percent flax to feedlot heifers resulted in steaks that had lower Warner-Bratzler shear force values, which suggests that steaks should be more tender when compared with steaks from heifers fed a corn-based control diet. However, Drouillard et al. (2004) reported no differences in steak shear force values from flax-fed cattle when compared with steaks from cattle fed control diets.

Swine

Growth and Carcass Composition

Because swine are monogastric, ALA is not biohydrogenated prior to the small intestine, and as a result, a greater percentage of dietary ALA is available for absorption. Romans et al. (1995a) fed ground flax at 0 percent, 5 percent, 10 percent and 15 percent of the diet to 48 barrows and noted no differences in ADG, hot carcass weight or percentage lean. In a companion study, Romans et al. (1995b) fed 15 percent ground flax to growing barrows and gilts for seven, 14, 21 or 28 days and again found no differences in performance or carcass traits.

Neither study reported differences in fat firmness or lean quality. Both studies indicated that flax inclusion in the diet increases ALA and EPA concentrations in muscle and fat tissues and levels increased as time-on-feed and dietary level increased.

Kouba et al. (2003) fed growing pigs 6 percent crushed flax for 20, 60 or 100 days and found no differences in animal growth or carcass composition when compared with hogs fed wheat and soybean meal. Hogs fed flax had higher muscle ALA and EPA levels than hogs fed the control diet, but surprisingly, ALA levels decreased between 60 and 100 d in pigs fed the flax diet. Levels of EPA decreased over time regardless of dietary treatment. Additionally, Fontanillas et al. (1998) fed linseed oil at 4 percent of the diet and reported increased levels of ALA and longer-chain omega-3 fatty acids in subcutaneous fat samples, compared with two sources of monounsaturated fatty acids.

Reproduction

Lawrence et al. (2004) added 5 percent flaxseed to basal sow diets and reported that flax addition decreased weaning-to-estrus interval (8.0 vs 7.4 d) and pre-weaning mortality (13.7 percent vs. 10.0 percent), along with increasing pigs weaned per mated sow (20.8 vs 20.3, annual production). Additionally, Stitt (1994) noted that feeding gilts and sows flax at 7.5 percent of the diet over two generations increased litter size (7.47 vs. 10.93, control vs. flax, respectively).

Other Species

Poultry

Research indicates that including flax in poultry diets can have positive effects on broiler performance and egg fatty acid profiles. Ajuyah et al. (1991) included 10 percent or 20 percent flax in broiler diets and found less carcass fat and larger leg weights in flax-fed chickens. Additionally, they reported increased omega-3 fatty acids in meat from chickens fed flax diets. In a companion study, Ajuyah et al. (1993) fed 15 pecent flax to broilers and determined that dark meat had higher levels of ALA than white meat, with meat from flax-fed broilers higher in omega-3 fatty acids, compared with meat from chickens fed the control diet.

Eggs can be enriched with ALA easily because the fat content of eggs is influenced to a large degree by the laying hen's ration (Jiang et al., 1991). Caston and Leeson (1990) reported that including 10 percent or 20 percent flax in laying hen rations increased ALA content in eggs 10-fold or 20-fold, respectively.

Scheideler et al. (1994) fed laying hens one of eight diets: a control diet and the control diet with added fish oil (1.5 percent DM), or whole or ground flax at 5 percent, 10 percent or 15 percent of diet DM. Hens fed 5 percent whole flax, 5 percent ground flax and 15 percent ground flax had reduced feed intake, compared with the control diet; however, flax-fed laying hens had greater egg production (percent). Egg ALA content increased linearly from 0.26 g/100 g fatty acids in the control diet to 7.07 g/100 g for eggs from hens fed 15 percent whole flax.

However, taste panel data noted that eggs from hens fed 10 percent or 15 percent ground flax had lower

flavor desirability scores than eggs from hens fed the control diet.

Other

Limited research on the effects of dietary flax has been conducted in other species. Neelley et al. (1997) reported that feeding flax oil to horses fed high-starch diets reduced incidences of laminitis. They stated that the reduction in the ratio of omega-3:omega-6, caused by a high-corn diet, increased the production of pre-inflammatory mediators, leukotrienes, which can cause laminitis.

To alleviate the effects of seasonal pruritus, an equine allergy that causes itchy lesions in horses, O'Neill et al. (2002) supplemented 1 lb/1,000 lb body weight of either flax or bran and reported that flax reduced induced allergic reactions. Campbell and Roudebush (1995) included flax in canine diets and visually determined that flax increased plasma levels of omega-3 fatty acids and that flax-fed dogs had healthier coats and skin.

Conclusions

Flax can serve as a useful source of nutrients for many classes of livestock. It is high in protein and an excellent source of energy and essential fatty acids.

Flax also can be used to fortify foods with omega-3 fatty acids. Research has shown that including flax in livestock diets increases the level of ALA, an essential omega-3 fatty acid, in the resultant meat, milk and eggs. Niche marketing to certain health conscious consumers could be used to add value to food products from flax-fed livestock.

For beef cattle, optimum dietary levels appear to be less than 10 percent, but much research still needs to be conducted to determine the potential interactions between dietary level and length of flax feeding. However, flax clearly should be processed for beef cattle.

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