FLAX
FEED INDUSTRY GUIDE

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INTRODUCTION

Flaxseed *(Linum usitatissiumum)* also known as linseed, is thought to be one of the world's oldest cultivated crops with evidence of cultivation dating back thousands of years. The crop is prized for its fibre and oil. The fibre, obtained from the stocks of the plant, is used to make fine linen and paper. The oil is used primarily for industrial purposes. The oil is probably best known for its function in the production of paints and floor covering (linoleum). The by-product remaining after oil extraction – flaxseed meal or linseed meal – is a source of protein used in livestock feeds, especially in the rations of ruminant animals. The seed is also used in livestock production for its medicinal properties, in particular for its functions as a laxative as well as for improving skin and hair quality.

Recently there has been a renewed interest in using flaxseed and flax oil in animal rations as it can be used to alter the fatty acid composition of egg and meat products and, therefore, provide functional health benefits for the consumer. The purpose of this guide is to provide practical information to users who wish to feed flaxseed to their livestock.

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List of abbreviations and terms

ALA (alpha-linolenic acid C18:3n-3), CLA (conjugated linoleic acid), DHA (docosahexaenoic acid C22:6n-3), EPA (eicosapentaenoic acid C20:5n-3), LA (linoleic acid C18:2n-6), Linseed meal (flaxseed product remaining following oilseed extraction), PUFA (polyunsaturated fatty acids).

SECTION 1 – HEALTH BENEFITS

Flaxseed has been consumed for centuries for its good flavour and for its nutritional properties. In recent years, as people have become more concerned about health, demand for flax in food and beverages, functional foods and dietary supplements has risen dramatically.

Typically flaxseed contains between 42 to 46% fat, 28% dietary fibre, 21% protein, 4% ash, and 6% carbohydrates. Flaxseed oil has a very healthy fatty-acid profile, with low levels (approximately 9%) of saturated fat, moderate levels (18%) of monounsaturated fat, and high concentrations (73%) of polyunsaturated fatty acids (PUFAs). The PUFA content comprises about 16% omega-6 fatty acids, primarily as linoleic acid (LA), and 57% alpha-linolenic acid (ALA C18:3n-3), an omega-3 fatty acid (Table 1).

Both LA and ALA are essential fatty acids (EFAs) since they cannot be produced by the body and must come from the diet. ALA can be converted in the body to eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Burdge and Wootton, 2002; Harper et al., 2006). EPA and DHA are also found in marine oils, primarily in fish oil. Omega-3 fatty acids have been shown to have numerous health benefits including a reduction in inflammation, blood pressure and decreased blood triglyceride levels and incidence of coronary heart disease. Omega-3 fatty acids are a special class of lipids which have a double bond at the 3 carbon from the methyl end. The unsaturated oil in most plant sources is rich in fatty acids with the first double bond 6 carbons from the methyl end of the molecule (omega-6) and, therefore, Western diets consist predominantly of high ratios of omega-6 to omega-3 fatty acids.

EPA is a 20 carbon fatty acid which has 5 double bonds with the first being 3 carbons from the methyl end (C20:5n-3). DHA comprises 22 carbons, has 6 double bonds with the first being found 3 carbons from the methyl end (C22:6n-3). EPA is a precursor to eicosanoids—compounds produced by the body that exert hormone-like activity. They are involved in the mediation of inflammatory responses, production of pain and fever, blood pressure regulation, induction of blood clotting, control of reproductive functions and regulation of the sleep/wake cycle. Eicosanoids produced from omega-6 fatty acids tend to promote inflammation, increased blood pressure and blood clotting, whereas those produced from omega-3 fatty acids, especially EPA, do not. DHA is also required for the normal growth and development of the fetus and infant.

Due to the role of omega-3 fatty acids in human health, the Institute of Medicine recommends that adult males and females consume 1.6 g/day and 1.1g/day of ALA, respectively (Anon, 2002). Traditionally, the primary source of omega-3 fatty acids in the diet was fatty fish but the amount consumed in Western cultures tends to be limited by availability and dietary preferences, so researchers have developed creative ways to incorporate the omega-3 ALA, EPA and DHA into foods found commonly in Western diets. Foods derived from feeding animals flaxseed and flax oil are described in this document.

Flaxseed contains approximately 28% dietary fibre in a ratio of soluble to insoluble fibre between 20:80 and 40:60 (Hadley et al., 1992). Flaxseed is also rich in lignans, phytoestrogens which have chemical structures similar to the human hormone estrogen that, despite being much weaker than human estrogens, can help balance hormone levels in the body. Flaxseed is one of the richest sources of lignans, providing 75 to 800 times higher levels than other plant sources (Thompson, 1995).

The major lignan in flax is seicoisolariciresinol diglucoside, commonly referred to as SDG. Once ingested, SDG is converted in the colon to enterodiol and enterolactone, which have shown promise in reducing growth of cancerous tumors, especially hormone-sensitive ones such as those of the breast, endometrium and prostate (Tham et al., 1998). Lignans and other flax components also have antioxidant properties and, hence, may reduce the activity of cell-damaging free radicals (Prasad, 2001).

Significant to the animal feed area is the protein component in flaxseed that is very similar to that of soybean protein. Flaxseed also contains a number of important essential minerals and minor amounts of water- and fat-soluble vitamins.

Research continues to expand the use of flaxseed for both animal health as well as to develop healthier animal products for humans.

TABLE 1. Fatty acid composition of No. 1 Canada Western Flax (10 year average, DeClercq, 2006)

FATTY ACID	CHEMICAL STRUCTURE	% IN OIL
Palmitic acid	C16:0	5.2
Steric acid	C18:0	3.4
Oleic acid (omega-9)	C18:1	18.1
Linoleic acid (omega-6)	C18:2N-6	15.0
Linolenic acid (omega-3)	**C18:3N-3**	**57.9**

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Photo courtesy of Saskatchewan Flax Development Commission.

SECTION 2 – PROCESSING

The majority of flaxseed is processed to extract oil for use in industrial products such as paints or floor coverings. Therefore, the primary objective of processing is to efficiently extract oil from the seed. Following oil extraction a meal is produced that is concentrated in protein and used in livestock feeds; this product is often referred to as linseed meal. The methods of oil extraction commonly employed are very similar to those used for other high fat oilseeds such as canola. The two most commonly employed processes are prepress solvent extraction and expeller press extraction. Prepress solvent extraction extracts virtually all of the oil using a combination of mechanical extraction and solvent extraction. In contrast, expeller processing relies solely on mechanical pressure to extract oil and leaves residual oil in the meal, typically greater than 5%. Since processing method has such a significant impact on oil content and, therefore, the energy content of the meal, it is important to understand the method of processing used.

Prepress Solvent Extraction of Flaxseed

Prepress solvent extraction uses a combination of mechanical pressure and chemical extraction and is the preferred oilseed extraction method for most large scale plants as it is the most effective method of extracting oil. Figure 1 shows a schematic of standard prepress solvent extraction used in the extraction of oilseeds such as flax and canola. It includes cleaning of the seed, preconditioning, flaking, cooking, expelling, solvent extraction, desolventization, cooling and discharge as final meal product.

The seed is typically cleaned to remove stones, chaff or dirt to prevent damage or wear on the processing equipment. The seed is then warmed to prevent it from shattering during the flaking stage. Flaking consists of passing the seed through a roller mill comprising two smooth-faced rolls with only a very small gap between them. The seed is fed between the rolls and crushed into a very thin flake. The objective of flaking is to rupture the cell walls and to increase the surface area for oil extraction. The seed is cooked to reduce the viscosity of the oil and to allow it to migrate out of storage bodies in the seed. This step is accomplished by feeding the seed into a stacked cooker which has a series of heated plates onto which the seed sits. The seed is swept over the heated plates and falls to the next plate until it exits the unit heated and, therefore, prepared for extraction.

Prepressing is achieved by feeding the flaked, heated seed into a mechanical expeller press. The expeller press consists of a heavy metal screw that forces the seed through a chamber that has fine openings in the wall to allow oil to squeeze through while retaining the solid portions of the seed. The screw is configured such that it pushes the seed against the outer wall of the chamber as it feeds it down the barrel. This compression effect forces the oil out of the small openings in the wall and is collected (Figure 2). This process extracts approximately half of the oil and prepares a cake or collet that is suitable for solvent extraction.

The presscake or collet exits the expeller and is conveyed into a solvent extractor. Hexane, a non-polar solvent, is flushed through the collet and solubilizes and absorbs the oil from the flax meal. After the oil extraction is complete, the solvent is allowed to drain out of the meal. The solvent is pumped into an evaporator and the hexane is boiled off leaving the oil for further refining. The solvent-laden meal is then conveyed into a solvent extractor, where it is heated by passing the meal over steam heated plates causing much of the hexane to evaporate. Steam is often purged through the meal in the final stages as well to strip the last remnants of the hexane from the meal. The hexane vapours are cooled, condensed and collected for use again.

The hot meal is then fed into a cooler where ambient air is blown through in order to cool and dry the meal. The screenings and gums are mixed into the meal which is then hammer milled in preparation for sale as a feed ingredient.

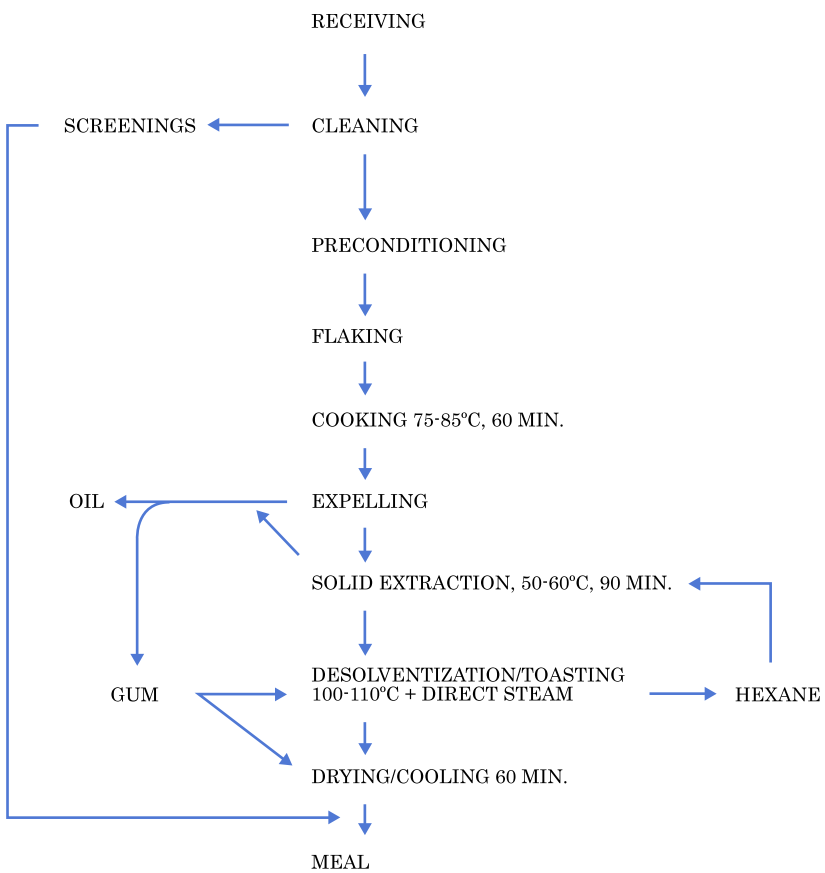

FIGURE 1: Schematic of standard prepress solvent extraction.

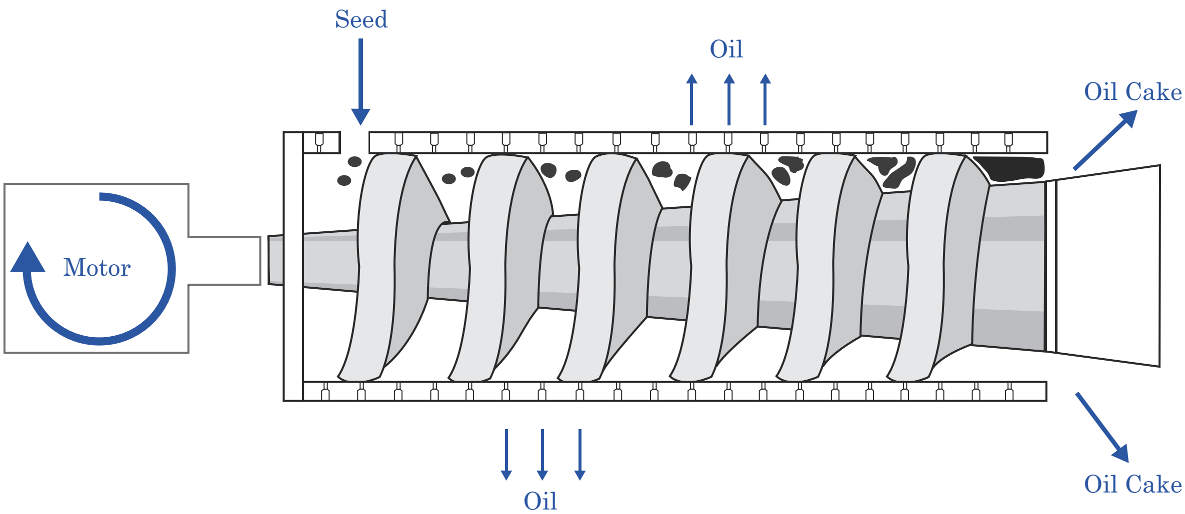

FIGURE 2: Cross section of an expeller press.

Mechanical Extraction of Flaxseed

Prepress solvent extraction is employed by most large crushing plants but the cost of building such a plant is very high (between $100 and $200 million) and, therefore, is not practical for small companies. Expeller plants can be economically constructed from small scale (<0.25 T/day) to large scale (1000 T/day) but they do leave residual oil in the meal. With the recent interest in incorporating flax oil into human diets, some choose to sell mechanically extracted oil – often referred to as cold pressed oil – on the basis that a solvent was not used in the process of extraction and this may appeal to some users. In addition, some companies are extracting oil for the local livestock industry to promote the production of omega-3 enriched products. In these cases mechanical extraction is often the method of choice due to the low capital investment required and the potential for small scale extraction. In some cases, feed companies can set up a mechanical extraction press for the production of oil and meal at the feedmill.

The meal product resulting from mechanical extraction (expeller meal or presscake) has a residual oil content of over 5% and offers a meal with elevated energy content as compared to solvent-extracted meal.

Mechanical extraction is conducted with the aid of an expeller press (Figure 2). Like prepress solvent extraction, the seed is often cleaned, conditioned, flaked and cooked prior to expelling the oil (Figure 1). However, unlike prepress solvent extraction, the objective is to extract as much oil as possible through mechanical pressure alone. Therefore, it is common practice to install two sets of expeller presses. The first press extracts approximately 50% of the oil; the cake is then fed into a second press and additional pressure is applied to drive out as much of the remaining oil as possible.

Photo courtesy of Saskatchewan Flax Development Commission.

SECTION 3 – NUTRITIONAL COMPOSITION

The typical nutrient composition of flaxseed, flax oil, expeller meal and solvent-extracted meal is shown in Tables 2-6. Flaxseed is a rich source of protein and energy; however, the seed does contain some unique anti-nutritional components that need to be considered when feeding this product.

TABLE 2. Typical chemical composition and metabolizable energy content[1] of flaxseed and expeller and solvent-extracted meals

COMPONENT	SEED	EXPELLER MEAL	SOLVENT MEAL	OIL
Moisture	93	91	88	-
Crude Protein (N x 6.25) %	22	31.5	33	-
Ether extract (%)	40.5	5.1	0.5	-
Crude fibre (%)	6.5	9.5	9.5	-
Ca (%)	0.25	0.40	0.35	-
P (%)	0.50	0.80	0.75	-
Ash (%)	-	6.0	6.0	-
Gross Energy (kcal/kg)	6530	4500	-	-
AME (kcal/kg)	3800	1850	1400	8150
AMEn (kcal/kg)	3750	2070	-	8100
TME (kcal/kg)	3960	2240	-	8610
TMEn (kcal/kg)	3750	2070	-	8280

[1] *Adapted from Feedstuffs 2008 Reference Issue and Buyers Guide, Lee et al. 1995, and DeClercq, 2006.*

TABLE 3. Typical amino acid content[1] (% as received) of flaxseed and expeller and solvent-extracted meals

AMINO ACID (%)	SEED	EXPELLER MEAL	SOLVENT MEAL
Methionine	0.37	0.53	0.48
Cysteine	0.42	0.56	0.58
Lysine	0.99	1.18	1.10
Tryptophan	0.22	0.47	0.48
Threonine	0.89	1.12	1.20
Isoleucine	1.07	1.50	1.80
Histidine	0.53	0.60	0.70
Valine	1.43	1.49	1.60
Leucine	1.43	1.87	2.00
Arginine	2.23	2.54	2.70
Phenylalanine	1.15	1.43	1.50

[1]*Adapted from Feedstuffs 2008 Reference Issue and Buyers Guide and Lee et. al. 1995.*

TABLE 4. Amino acid digestibility (%) of flaxseed and expeller and solvent-extracted meals

COMPONENT	SEED[1] TAAA[2]	SEED[1] AAAA[3]	EXPELLER MEAL[1] TAAA[2]	EXPELLER MEAL[1] AAAA[3]
Methionine	76	73	79	76
Lysine	81	70	80	69
Threonine	71	61	74	65
Isoleucine	83	76	82	76
Histidine	85	78	79	72
Valine	80	72	80	74
Leucine	85	75	81	75
Arginine	87	81	88	82
Phenylalanine	83	78	85	80

[1]*Lee et al. 1995.*
[2]*TAAA=True Amino Acid Availability.*
[3]*AAAA=Apparent Amino Acid Availability.*

TABLE 5. Typical vitamin content of flaxseed and expeller and solvent-extracted meals

VITAMINS	SEED[1]	EXPELLER MEAL[1]	SOLVENT MEAL[1]
Vitamin A (IU/g)	-	0.3	-
Vitamin E (mg/kg)	18.9	7.7	5.8
Thiamin (mg/kg)	7.0	2.60	6.6
Riboflavin (mg/kg)	4.5	4.10	4.10
Pantothenic acid (mg/kg)	-	16.5	16.5
Folic acid (ug/kg)	-	2900	1300
Choline (mg/kg)	3150	1672	1760
Niacin (mg/kg)	41.0	37.4	32.8

[1]*Feedstuffs 2008 Reference Issue and Buyers Guide*.

TABLE 6. Typical mineral content of flaxseed and expeller and solvent-extracted meals

MINERALS	SEED[1]	EXPELLER MEAL[1]	SOLVENT MEAL[1]
Sodium (%)	0.08	0.11	0.14
Potassium (%)	1.50	1.24	1.38
Magnesium (%)	0.50	0.58	0.60
Sulphur (%)	-	0.39	0.39
Manganese (ppm)	-	39.4	37.6
Iron (ppm)	236	200	300.0
Copper (ppm)	22	26.4	25.7
Zinc (ppm)	91	-	-
Selenium (ppm)	-	0.5-1.0	0.5-1

[1]*Feedstuffs 2008 Reference Issue and Buyers Guide.*

Anti-Nutritional Components

Flax contains the cyanogenic glycosides called linustatin, neolinustatin and linamarin. These compounds are degraded by ß-glucosidase in the large intestine and may cause the release of hydrogen cyanide, albeit in small amounts. Hydrogen cyanide is a powerful respiratory inhibitor if absorbed in sufficient quantities. The primary cyanogenic glycoside in flaxseed is linamarin and it ranges from 0 to 300mg/kg. Heat treatment of the seed such as that encountered during oil extraction tends to denature the ß-glucosidase preventing the formation of hydrogen cyanide. Shen et al. (2005) suggests that part of the positive effects of heat treatment of flaxseed may be due to the denaturation of ß-glucosidase and, therefore, the prevention of any negative effect of linamarin. However, in most cases, mature flaxseed is fed without heat treatment with little or no impact of linamarin being observed. Linamarin is, however, concentrated in immature seeds and could have a negative impact on animal performance if fed without heat treatment.

Flax contains a vitamin B_6 (pyridoxine) antagonist called linatine. The concentration typically ranges from 20-100 mg/kg. Occasionally symptoms of vitamin B_6 deficiency can be observed in broiler chickens fed flax and, therefore, it is recommended that diets containing flaxseed or meal be supplemented with additional pyridoxine to offset the potential negative effects of linatine on this vitamin.

Flax has been commonly used for its therapeutic effects in livestock including alleviation of constipation and enhanced digestive tract functions. Mucins (mucilage) are water soluble, indigestible, mucilaginous carbohydrates composed of galactose, xylose, arabinose, rhamnose and galacuronic acid sub-units that absorb water and increase intestinal viscosity. These mucins are likely responsible for the therapeutic effects of feeding flaxseed. Mucilage is found in the outer hull of the seed and accounts for approximately 8% of the weight of the seed. Feeding flaxseed can result in reductions in poultry performance, especially when fed to young birds. Increased digesta viscosity due to the consumption of high levels of mucilage is likely the cause of the losses in performance (Alzueta, et al. 2003). Slominski et al. (2006) examined the potential to increase nutrient utilization with a combination of fibre-degrading enzymes. They demonstrated a reduction in viscosity and increased performance using a cocktail of enzymes; however, they concluded that an enzyme that specifically targets flax mucilage is required and to date no such enzyme is currently commercially available. Since young animals are most sensitive to the negative affect of increased intestinal viscosity, flaxseed or meal inclusion in young poultry diets should be avoided. In addition, flaxseed should be introduced gradually to prevent digestive upsets.

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SECTION 4 – POULTRY

Flaxseed and meal have traditionally been used primarily in equine and bovine diets and laying hen rations. However, flax can be included in poultry diets if used in the proper proportions and formulated appropriately. Several companies are now marketing poultry products that are enriched in omega-3 through the feeding of flaxseed. The most popular commercial product is omega-3 eggs available in most grocery stores throughout North America. Research is also being conducted with flax to produce omega-3 enriched poultry meat products.

Laying Hens

Flaxseed meals can be fed to laying hens as a source of protein and energy. It is very similar to canola meal in protein and energy content but tends to be limiting in lysine. The amino acid digestibility is less than that of soybean meal, so it is important to formulate on a digestible amino acid basis. Flax meal, however, should be limited to 3% of the diet in young birds and 10% in the laying ration due to the potential anti-nutritional effects of mucilage, linatine and linamarin (see page 10).

Given the many positive effects of omega-3 fatty acids, many consumers are looking for convenient ways to incorporate them into their diets. Consuming eggs enriched with omega-3 fatty acids is a convenient way to do so. The fatty acid profile, including the omega-3 content of eggs is affected by dietary fat source. Research studies consistently demonstrate an increase in the omega-3 fatty acid content of eggs, especially ALA, when laying hens are fed flax oil or flaxseed. For example, Bean and Leeson (2003) conducted a long term feeding study with 10% flaxseed in a laying hen ration consisting primarily of corn and soybean meal. Flax increased the total omega-3 content of the eggs from 99.8 to 415.4 mg/50g egg. ALA increased from 38.5 to 306.3 while DHA increased from 53.3 to 83.7 mg/50 g egg, when fed 10% flaxseed.

Several studies have demonstrated that feeding flaxseed can potentially reduce feed intake, body weight and egg production, especially in the early stages of production. However, Bean and Leeson (2003) demonstrated that feeding 10% flax did not impact egg production if the flaxseed is phased into the diet over a three week period starting at 28 weeks of age. At weeks 28, 29 and 30 the hens were fed 4, 8 and 10% flax respectively. Similarly at 54, 55 and 56 weeks of age the flax was phased out of the ration. Other studies that did not phase the flax into the diet did observe negative effects in performance. In some cases the metabolizable energy content of the seed was overestimated and likely contributed to the reductions in performance as well. Therefore, it is recommended that flax be introduced in a gradual manner and only after the birds have reached maturity and that a conservative value for metabolizable energy be utilized.

Flax oil can be fed to laying hens to increase the omega-3 content of the eggs with no negative effects on performance. Grobas et al. (2001) found that ALA increased from 6.3% to 40.2 and 48.3% of the total fat when laying hens were provided 0, 5 and 10% flax oil, respectively. Unfortunately, flax oil is not commonly available to the livestock industry so feeding flaxseed is the more common practice.

Some studies have indicated an increased incidence of liver hemorrhage in laying hens fed flaxseed or oil (Schumann et al., 2000). It is believed this effect is likely due to the increased level of oxidation of the polyunsaturated fats like ALA. Other studies, however, such as the one conducted by Bean and Leeson (2003) did not observe this effect. Leeson et al. (2007) observed a reduction in liver hemorrhage when supplementing a flax diet with 250 ppm lutein, suggesting the addition of anti-oxidants to the diets of laying hens may prevent liver hemorrhage and is therefore recommended.

Typically flaxseed comprises between 10 and 20% of the diet in order to produce omega-3 enriched eggs. In Canada, food products must contain greater than 300 mg of omega-3 fatty acid per serving in order to be labeled as an omega-3 enriched product. Since one 50g egg is considered a single serving, eggs from laying hens fed 15% flaxseed would qualify since they normally contain approximately 400 mg total omega-3 fatty acid/50g egg. Feeding greater than 20% flaxseed is not recommended as the potential for reduced performance due to anti-nutritional components is too great.

Broilers

Flaxseed and meal products can be fed to broiler chickens in small amounts. Solvent-extracted meal tends to be limited in energy and lysine for broiler chickens. In addition, feeding flaxseed or meal has been shown to depress growth performance and promote diarrhoea in broiler chickens. The depressed growth rate is likely due to the negative effects of linatine, a vitamin B_6 antagonist, combined with the effects of the intestinal viscosity caused by mucilage. Therefore, the maximum recommended inclusion of flaxseed or meal in broiler diets is 3%. If more than 10% flax is incorporated into the diet, supplementation with additional vitamin B_6 is recommended to overcome the negative effects of linatine.

Flax oil can be used to increase the omega-3 content of the broiler carcass without negatively affecting bird performance. Rymer and Givens (2006) demonstrated an increase of ALA from 30 to 99.4 and 139 mg/100g of white meat when broilers were fed 2 or 4% flax oil, respectively. EPA increased from 7.2 to 7.8 and 16.8 mg/100 g white meat when fed 2 or 4% flax oil, respectively. However, feeding flax oil had no effect on DHA content of the white muscle in the same study. Similarly, feeding flax oil increases the omega-3 fatty acid content in dark muscle. ALA content of dark meat increased from 57 to 158 and 233 mg/100g when broilers were fed 2 or 4% flax oil, respectively. EPA increased from 6.2 to 7.9 and 16.1 mg/100 g in white meat when fed 2 or 4% flax oil, respectively.

González-Esquerra and Leeson (2000) fed 10% flax to broiler chickens and demonstrated an increase in ALA from 11 to 54 mg/100g cooked skinless breast meat and from 43 to 183mg/100g cooked skinless thigh meat. The long chained omega-3 fatty acid content also increased from 17 and 0 to 89 and 23 mg/100g of cooked skinless breast meat and thigh meat, respectively. However, bird performance is typically reduced by feeding this level of flaxseed. Therefore, feeding greater than 3% flaxseed to broilers is not recommended unless a sufficient premium for the product can be achieved.

Processing of the Seed

Processing of seed improves nutrient utilization and can potentially reduce the negative impact of anti-nutritional components such as linatine. Grinding the seed also improves the metabolizable energy by as much as 16%.

Shen et al. (2005a) fed broiler chickens 12% flax from 1-21 days and 15% from 22-40 days. Feeding whole flax reduced body weight, feed intake and feed efficiency but feeding flaxseed that had been previously pelleted and mashed significantly improved body weight gain, feed conversion efficiency and feed intake. However, the overall bodyweights of birds fed 12 and 15% processed flaxseed were less than the control diet indicating the inclusion level was too high even with effective processing.

Shen et al. (2005b) examined the effects of processing including pelleting, autoclaving, and microwave roasting on nutrient utilization in leghorn roosters. Pelleting the seed three times increased fatty acid retention by 29%. Microwaving for four minutes increased fatty acid utilization by 39% and autoclaving increased fat utilization by 20%, demonstrating the positive effects of heat treatment on flaxseed utilization. Nitrogen retention was also significantly improved by heat and/or physical processing.

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SECTION 5 – SWINE

Flax products can be fed to swine; however, it has traditionally been directed into ruminant diets. Due to recent interest in the production of meat products enriched in omega-3 fatty acids and the potential to improve sow productivity and piglet health, flax products are now being used in swine diets with increasing frequency.

Starter Rations

Flax meal can be included in starter rations up to 3% without adverse effects on growth and feed intake. However, feeding greater quantities to very young stock can result in reduced performance due to the negative effects of mucilage, linatine and linamarin. Jansman et al. (2007) substituted 8.5% expeller meal or 12.5% seed into the diets of newly weaned pigs in an attempt to study the potential positive effects of the ALA and phenolic compounds present on gut health and the immune system. However, when flax was included at these levels, weight gain was depressed. It is believed that young animals have limited capacity to overcome the negative effects of the anti-nutritional factors present in flax (see page 10).

Flax oil can be used in all hog rations including the starter ration without negatively affecting performance. It has been hypothesized that the supplementation of starter rations with omega-3 fatty acids may improve the health status of the animal due to their effects on the immune system via regulation of eicosanoids (Turek et al., 1996). However, further study is required to determine the effectiveness of this approach.

Grower and Finishing Rations

Generally flaxseed and meals can be fed up to 10% of the diet to grower and finishing hogs without negative effects on performance. Flax is an intermediate source of protein with a composition very similar to that of canola. However, the amino acid balance of flax is poorer than canola meal as it is deficient in lysine and tryptophan and, therefore, cannot be used as a sole source of supplemental protein in cereal-based diets. Numerous studies have demonstrated the inclusion of flax products in the diets of growing hogs without negative effects on performance. Early studies indicated flax meal could be included in swine rations up to 25% of the diet without affecting performance. More recently Matthews et al. (2000) fed 30 kg pigs diets with 5 or 10% flaxseed without affecting production performance. However, Thacker et al. (2004) examined the impact of feeding a 50/50 flaxseed/pea mixture that had undergone an extrusion process and indicated reductions of performance when included at 30% of the diet. Feeding 22.5% of the flax/pea mixture in the grower diet had no effect on animal performance, however. Batterham et al. (1991) fed a diet containing 30% prepress solvent-extracted flax meal to hogs from 20 kg to 45 kg body weight and observed reductions in body weight, indicating flax should not be fed at this level to pigs under 45 kg. Batterham et al. (1991) concluded that the hogs under 45 kg were negatively affected by the anti-nutritional factors present in the meal.

Numerous studies have demonstrated the use flaxseed in finisher rations without affecting animal performance. Romans et al. (1995a) fed finishing hogs 0, 5, 10, and 15% ground flaxseed to hogs for 25 days prior to slaughter. Inclusion of the flaxseed in the diet had no effect on animal performance. In a follow-up study Romans et al. (1995b) fed 15% flax for 28 days prior to slaughter and once again did not observe any impact on animal performance. Matthews et al. (2000) fed rations with 0, 5 or 10% whole flaxseed and did not observe any impact on animal performance. Thacker et al. (2004) fed a 50/50 blend of peas and flax that had been processed through an extruder and observed equal performance up to 18% inclusion in the diet; however, at 24% they started to observe a depression in weight gain. Solvent-extracted flax meal can also be fed to finishing hogs; however, it is not commonly used due to the low energy content (Table 7) and low lysine content (Table 3).

TABLE 7. Energy content of flaxseed and expeller and solvent-extracted meals

COMPONENT	SEED	EXPELLER MEAL	SOLVENT MEAL	FLAX OIL
DE (kcal/kg) Boland 1990	4253	3340	3060	8380
ME (kcal/kg)	2580	2000	2400	8220
NE (MJ/kg)	13.1	8.4	7.3	29.8

Enrichment of Pork Products with Omega-3 Fatty Acids

Due to the positive impact of including omega-3 fatty acids in human diets, there is significant interest in enriching the omega-3 fatty acid content of meat and lard products produced by swine. Like other monogastric species such as poultry, the fatty acid profile of the meat and fat is directly affected by the source of fat in the diet. Therefore, it is possible to change the fatty acid profile, especially the ratio of omega-6 to omega-3 fatty acids, by feeding flax oil or flaxseed, a rich source of omega-3 fatty acids.

Romans et al. (1995a) examined the effect of feeding graded levels of flax to pigs 25 days prior to slaughter. Feed containing 0, 5, 10, and 15% ground flax increased the ALA from 10 to 23, 37 and 53 mg/g inner backfat, respectively. EPA increased from 0.09 to 0.20, 0.28 and 0.38 mg/g backfat, when fed 0, 5, 10 and 15% ground flaxseed respectively, clearly indicating the potential to increase the omega-3 content of pork products by feeding flaxseed in the finishing phase. Specht-Overholt (1997) also observed significant improvements in ALA concentrations in the meat of swine fed 15% flaxseed. After 28 days, ALA concentration increased from 1.1% of the fat to 8.8% while those fed 15% flax for 42 days increased from 1.3% to 12%.

Romans et al. (1995b) examined the impact of feeding duration on omega-3 enrichment and concluded flax should be fed for a minimum of 21 days prior to slaughter to achieve optimal concentration. Fontanillas et al. (1998) fed 4% flax oil for 60 days and determined omega-3 content by biopsies. They observed an increase in ALA from 1.14% to 4.94, 7.40, and 7.89% after 17, 31, and 60 days feeding, respectively. These data were used to model rates of change in deposition of fatty acids. Fontanillas et al. (1998) concluded that 70% of the maximum ALA enrichment is achieved after only feeding 30 days while 95% is achieved if fed 60 days.

Omega-3 enriched pork products, produced through the feeding of flaxseed, are now available commercially in both Canada and the United States. These products are slowly gaining in popularity as they not only deliver omega-3 fatty acids into our diet but are also reported to result in a juicier and tastier meat product.

Sow Rations

Flax has often been used for its medicinal properties. Flax is occasionally used at the time of parturition to alleviate constipation but there is growing interest in the effects of the omega-3 fatty acids. These compounds alter the immune and inflammation responses through the modification of eicosonoids which play a major role in the inflammatory process. In addition, flax contains secoisolariciresinol diglycoside (SDG), a phenolic lignan that is converted to mammalian lignans by the micro-organisms in the hindgut. The imunomodulating effects of omega-3 fatty acids combined with the potential hormonal effects of the phytoestrogens may have a positive effect on sow productivity and the health of the piglets. To study the effect of flaxseed on the long term productivity of sows and the performance of the offspring, Lawrence et al. (2004) fed 5% flaxseed to 2400 sows and a control diet to 4800 sows. Performance over three parities was studied. Feeding flaxseed increased the number of pigs weaned per mated sow by 0.5 per year over the control group. They also observed an increase in birth weight, weaning weight in the third parity, improvements in farrowing rate and percentage of sows rebred within seven days. Further research is needed to completely understand the potential impact of feeding flaxseed in the sow ration, but based on the research to date the addition of 5% ground flaxseed may have long term health and production benefits.

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SECTION 6 – RUMINANTS

Flax products are an excellent source of protein and energy for ruminants. The anti-nutritional components that can affect monogastric animals such as mucilage are effectively neutralized in the rumen and may even stimulate rumen function. It appears flax products, especially the by-products of flax processing, have been used effectively in beef and dairy rations since the beginnings of agriculture. Bethke et al. (1928) reported successfully using 10% linseed meal in beef calf diets without affecting animal performance. Weber (1934) studied the relative value of linseed meal and reported enhanced growth and feed conversion. They also reported improved carcass fat content and "glossier coats of hair." Flax products are still widely believed to be useful in promoting health, skin and hair quality and are often included in rations for show cattle for this reason.

Typically the fat content of ruminant diets must be limited to less than 5% of the dry matter of the diet due to the negative effects of free fat on rumen function and reduced feed intake and performance. However, in many cases it is desirable to increase the energy content of rations when feed intake is limited. Flaxseed offers the advantage of packaging the fat in such a way so as not to negatively affect rumen function while promoting feed intake. Therefore, it can be an effective way to increase the energy content of the diet. Recently there has been interest in using whole fat flaxseed for beef or dairy animals. The primary objective is to enhance the omega-3 fatty acid and conjugated linoleic acid content of the meat products but some research has also suggested it enhances disease resistance due to the potential immuno-modulating effects of ALA.

Beef Cattle

Linseed meal can be used effectively as a protein source for beef cattle at all stages of life. It is very palatable with a high protein and energy content (Table 8) and can be used as the sole protein supplement. Similarly, whole fat flaxseed can be used in beef rations as a source of protein, energy and omega-3 fatty acids.

TABLE 8. Typical fibre ruminant digestible protein and energy composition of flaxseed and expeller and solvent-extracted meals

COMPONENT	SEED	EXPELLER MEAL	SOLVENT MEAL
TDN (%)[1]	115	82	78
CP (%)[1]	25.6	37.9	38.3
Ether Extract (%)[1]	38.3	6.0	1.5
Crude Fibre (%)[1]	6.7	9.6	10.1
NDF (%)	20.2[3]	22.6[2]	25.9[2]
ADF (%)	12.4[3]	12.8[2]	17.3[2]
Potentially degradable Crude Protein (% of CP)[2]	-	75.4	67.2
NEm (Mcal/kg)[1]	3.15	2.00	1.87
NEg (Mcal/kg)[1]	1.63	1.34	1.23
NEI (Mcal/kg)[1]	2.68	1.89	1.78
Ca (%)[1]	0.23	0.45	0.43
P(%)[1]	0.55	0.96	0.89

[1]*Adapted from Feedstuffs 2008 Reference Issue and Buyers Guide.*
[2]*Adapted from Khorasani et al. 1994.*
[3]*Adapted from Gonthier et al. 2004.*

Creep feeds

Creep feeding is the practice of providing supplemental feed to nursing calves. The objective is to increase weaning weights and to prepare the calves for grain-based diets. Researchers at the North Dakota State University Central Grasslands Research Extension Center (Maddock et al., 2006) examined the potential to use ground flaxseed in creep feeds. Steer calves were provided a creep feed containing either 12.5 or 25% flax and there was no effects on average daily weight gain or feed intake as compared to the control creep feed. The diets containing 12.5% flax appeared to improve feed intake upon receiving; however, there was a tendency towards reduced performance at the 25% level.

Feedlot rations

Flaxseed can be effectively used in feedlot rations. Several studies have demonstrated the use of up to 20% flaxseed in the diet without negatively affecting performance. Flaxseed has high levels of energy and protein and promotes feed intake and weight gain and, therefore, is often economical to include in the ration even when the price is three or four times that of corn. Flaxseed has also been shown to offer additional benefits over its nutritional value alone. Drouillard et al. (2002) demonstrated increased feed intake in the critical first few days in the feedlot. The transition into the feedlot can be a stressful experience for newly weaned calves and they are prone to illness as a result. The objective is to transition the animals into the feedlot, minimize stress and disease, and maximize feed intake. Flax is a highly palatable feed ingredient and contains high levels of nutrients. Inclusion in the initial ration seems to promote feed intake and in some instances reduced incidence of disease (bovine respiratory disease) are observed (Drouillard et al., 2002). It is hypothesized that the immune status of the animal is enhanced by the omega-3 fatty acids present in the flax and that they reduce the inflammatory response, therefore, promoting feed intake and the overall well-being of the animals.

Feeding flaxseed may also improve carcass quality. Drouillard et al. (2002) have also observed increased marbling and grade scores when the finishing diet was supplemented with ground flaxseed.

Impact of flaxseed on fatty acid content of meat products

The fatty acid profile of meat products from beef cattle can be altered by feeding flax. Several studies have demonstrated the ability to increase the omega-3 content of meat products by feeding flaxseed. Unlike monogastric species, it is not possible to feed large quantities of oil to the animal as it will negatively affect the function of the rumen, reduce feed intake, and, therefore, the performance of the animal. Therefore, it is necessary to provide the fat in a protected form so it does not significantly affect ruminal function. Flaxseed (ground or rolled) on the other hand, can be added to the diet without affecting performance as the seed provides a degree of protection from solubilization in the rumen.

Given the many benefits of increasing the omega-3 content of human diets through modifying the fatty acid composition of meat products, numerous studies have examined the potential to modify the fatty acid profile of beef products by feeding flax. Much of the unsaturated fat fed to beef cattle is hydrogenated in the rumen, making it difficult to make dramatic changes in unsaturated fatty acid composition as is commonly observed when feeding pigs or chickens. In addition, the greater the degree of unsaturation the more likely the fat will be hydrogenated. Approximately 90% of the ALA in flax oil is hydrogenated and 80% of the LA is hydrogenated. However, in spite of the hydrogenation, feeding flaxseed increases the omega-3 content of both the subcutaneous and intramuscular fat deposits.

Aharoni et al. (2004) fed 8% flaxseed to bull calves and observed an increase in ALA from 3.2 to 9.3 g/100g of intramuscular fat. Mach et al. (2006) fed bull calves 0, 3.6, 11.2 or 18% flaxseed during finishing and observed an increase in total omega-3 fatty acids of approximately 0.48 to 2.25 g/100g fatty acids when fed the highest level of canola and flaxseed respectively. The majority of the change in omega-3 content is ALA, the predominant fatty acid in flax.

In long term studies there is also a two to four fold increase in the EPA but there is generally very little change in DHA concentration.

Conjugated linoleic acid (CLA) is a unique fatty acid found in ruminant products that has been shown to reduce tumour growth and, therefore, may have beneficial effects in preventing cancer in humans. CLA occurs rarely in nature but is produced by ruminants by partial hydrogenation of ALA or LA in the rumen to trans-vaccenic acid (C18:1*trans*-11) and then converted to (C18:2c9,t11 CLA) or (C18:2c10,t12 CLA) in the intramuscular fat or mammary gland. CLA content of the meat is affected by both forage and fat content of the diet. Many forage products contain LA or ALA which can be converted into CLA; therefore, high forage diets tend to promote enrichment of the meat. Feeding flaxseed also promotes the deposition of CLA in the ruminant animal. Feeding a combination of high forage content and flaxseed tends to result in the greatest enrichment of the meat with CLA.

Aharoni et al. (2004) fed 8% flaxseed to bull calves fed a diet containing either 28 or 42% forage on a dry matter basis. The high forage diets were most responsive to feeding flax which increased the CLA content from 4.0 to 6.7 g/100g fatty acids in the longissimus muscle.

Dairy Cattle

Linseed meal is an excellent protein supplement for use in dairy rations and can be used as the sole protein supplement in the concentrate. It is highly palatable and does not affect dry matter intake. The protein quality for dairy is similar to canola meal and ranks higher than other commonly used protein sources such as soybean meal, brewers dried grains, and feather meal (Arambel and Coon, 1981). Expeller-processed meal contains higher levels of fat and, therefore, energy (Table 8) but has a higher rate of ruminal crude protein degradation. Solvent-extracted meal is often the preferred source for dairy rations as it has a higher level of ruminal by-pass protein due to protein denaturation during desolventization, but it still retains a high level of total tract protein digestibility (Khorasani et al. 1994) and, therefore, supports high levels of milk production, milk fat, and protein content.

Flaxseed in dairy rations

Omega-3 fatty acids have been shown to improve the reproductive performance of dairy cattle. However, feeding significant quantities of oil (greater than 5%) directly to ruminants is not practical as it will negatively affect rumen function and, therefore, feed intake and milk production. Supplemental fat is often fed as a calcium salt to prevent rumen upset, but these salts are often very expensive and contain very little omega-3 fatty acids. The oil in flaxseed, however, is encapsulated in such a way that it does not interfere with rumen function. Feeding ground flaxseed is a practical and often cost effective way to introduce oil into the diet of high producing dairy animals and thereby supplying the much needed energy for milk production. In addition, flax contains very high levels of the omega-3 fatty acid ALA and this has been shown to have additional benefits for the dairy animal.

Petit et al. (2001) was the first to demonstrate that feeding flaxseed to dairy animals not only supports high levels of milk production but also increases reproductive function. Since that time several other studies have also shown that feeding flaxseed reduces the level of embryo deaths, increases follicle size and increases the size of the corpus luteum and the size of the large dominant follicle and, therefore, increases reproductive performance.

Ground flaxseed can be fed up to 15% of the dry matter of the diet without negatively impacting dry matter feed intake of the cow. Flaxseed can also be used to maintain milk production, milk fat and milk protein yield during the hot summer months when feed intake is often otherwise depressed due to heat stress. It is becoming common practice to include 1 kg of ground flaxseed/day for dairy cows to achieve increased reproduction and to incorporate energy into the diet.

The seed should be ground to increase nutrient availability but due to the potential for oxidation of the polyunsaturated fatty acids the product should not be stored in the ground form for more than two the seed prior to feeding increases the by-pass value of the protein. Gonthier et al. (2004) examined the effects of heat treating flaxseed prior to feeding. They micronized the seed at 115°C for 90 seconds or extruded the seed at 155°C for 43 seconds. Micronization significantly reduced ruminal protein digestibility and increased post-ruminal protein digestibility. Extrusion cooking, however, did not enhance ruminal protein by-pass values. The extrusion process appears to have increased nutrient disappearance in the rumen due to the effects of shear force and, therefore, counteracted the positive effects of heat treatment.

TABLE 9. Effect of feeding whole flaxseed (10.4 and 10.8% of dry matter) on embryo mortality and corpus luteum size in dairy cows

	FLAXSEED	MEGALAC	MICRONIZED SOYBEANS
Total Embryo Mortality	0	15.4	8.0
Corpus Luteum Size (mm)	19.1	18.3	16.3

Adapted from Petit and Twagiramungu (2006).

TABLE 10. Effect of feeding whole flaxseed (10.4 and 10.8% of dry matter) on milk production and milk composition between calving and 16 weeks of lactation

	FLAXSEED	MEGALAC	MICRONIZED SOYBEANS
Dry Matter Intake (kg/d)	19.4	18.3	18.7
Peak Milk yield (kg/d)	40.1	37.5	38.8
Millk Production (kg/d)	35.7	33.5	34.4
Milk Fat (%)	3.81	4.14	3.70
Milk Protein (%)	2.98	2.86	2.87
Milk Lactose	4.71	4.57	4.70
4% FCM (kg/d)	34.5	33.7	32.9

Adapted from Petit (2002).

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SECTION 7– HORSES

Flax products are commonly used in horse rations and are often the preferred source of protein. Flax can be used as the sole protein supplement comprising as much as 15% of the dry matter in the diet. The lysine content of the meal is too low, however, for young developing horses (Hintz et al., 1971) and will need to be supplemented into the diet to maximize growth and development.

Ground flaxseed or expeller-processed meal are thought to impart a glossy coat to the animal due to the oil content. Linseed meal is highly palatable and the mucilage also acts as a mild laxative and helps prevent digestive upset such as colic. Flax oil, ground flaxseed or expeller-processed meal can also be used as a source of essential fatty acids in the diet.

TABLE 11. Nutritional value of linseed meal for horses (dry matter basis)

	DE (Mcal/kg)	TDN%	Crude Protein (%)	Digestible Protein(%)	Lysine (%)	Crude Fibre (%)
Solvent-extracted meal	3.04	69	38.9	27.6	1.34	10

Adapted from Nutrient Requirements of Horses, 1978. National Academy Press, Washington, DC.

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SECTION 8 – AQUACULTURE

Fish are an important source of omega-3 fatty acids in human diets but the volume of fish caught in the wild is not keeping pace with the ever increasing demands for fish products. As a result, aquaculture has become a very important source of fish for human consumption but highly valued species such as salmon require large amounts of protein and oil in their diet. Traditionally the primary source has been fish meal and oil from rendered fish caught in the wild but the supply of fish meal and oil is not adequate to meet demands for this growing industry. Numerous studies have shown that vegetable oil, including flax oil, can be used in fish diets to replace fish oil without affecting growth performance (Chen et al. 2006). The fat composition of fish is a direct reflection of the oil used. Unlike feeding a diet high in saturated fats or omega-6 fats, feeding a diet high in flax oil will result in a meat product that is desirable to consumers. Flax oil can be fed to fish and completely replace the fish oil in the diet. Since the oil is high in omega-3 fatty acids, the fish will retain a desirable fatty acid profile (Drobna et al., 2006; Menoyo et al., 2005). The oil is prone to oxidation so an anti-oxidant should be added to the oil to prevent rancidity.

The oil in flaxseed is naturally protected from oxidation so it would seem wise to feed the seed directly to fish; however, the mucilage and fibre negatively affect nutrient absorption in most fish species making it impractical to feed. Researchers at the University of Saskatchewan have studied the potential to use processed flaxseed in the diets of rainbow trout. Drew et al. (2007) reported significant improvements in performance when the mucilage was removed by hot water extraction; however, this technology is not yet being applied commercially.

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