

# Optimization of Feed Peas, Canola and Flaxseed for Aqua feeds: the Canadian Prairie Perspective

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## Abstract

Supplies of marine fish oils and fish meal are limited and continued growth in aquaculture production dictates that substitutes must be found that do not compromise fish performance and product quality. When selecting potential vegetable protein and lipid sources as substitutes for fish meal and fish oil in coldwater aquatic diets, protein and energy availability in addition to the content of polyunsaturated fatty acids must be considered. Literature studies demonstrate that further processed plant protein and energy ingredients are good alternative feed ingredients for aquatic species.

Worldwide, Canada is one of the largest producers of field peas, canola and flaxseed with the greatest amount of production occurring in Saskatchewan. Enhanced market opportunities for the use of peas, canola and flaxseed, either locally or abroad, would be beneficial to producers in western Canada. The aqua feed industry provides a unique opportunity for processed pulse and oilseed crops since feeds for use in aquaculture are the fastest growing sector of the animal feed industry worldwide.

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## Introduction

Today, more than 30 percent of the world's seafood is grown in aquaculture facilities with demand continuing to grow. Developing aqua feed ingredients that promote fish culture technologies in a sustainable manner, without adversely affecting the environment, will be a priority for many years to come. The objective of this review is to give a brief overview of how Western Canada's most common crops – field peas, canola, and flaxseed – can be further processed to become value-added feed ingredients that promote the sustainability of the vital aquaculture industry.

Nutritionally, peas, canola and flaxseed offer excellent sources of nutrients and energy. Economically, peas, canola and flaxseed offer a consistent, dependable and affordable supply of ingredients from year to year. World trade in oilseeds, vegetable oils and protein meals has sharply increased in the preceding two decades largely the result of rising worldwide incomes, larger populations and food safety concerns (Agriculture and

Agri-Food Canada, 2004). This has led to the replacement of animal protein meals in Thiessen, D. 2004. Optimization of Feed Peas, Canola and Flaxseed for Aqua feeds: the Canadian Prairie Perspective. In: Cruz Suárez, L.E., Ricque Marie, D., Nieto López, M.G., Villarreal, D., Scholz, U. y González, M. 2004. Avances en Nutrición Acuicola VII. Memorias del VII Simposium Internacional de Nutrición Acuicola. 16-19 Noviembre, 2004. Hermosillo, Sonora, México

intensively raised livestock rations. Plant protein meals and vegetable oils have also found increased acceptance in aquaculture diets. Research in Canada and worldwide has shown that the maximum potential of pulses and oilseeds targeted for the aqua feed industry can be achieved through fractionation and further processing.

## **Peas**

### *Production*

Canada is the largest producer and exporter of dry peas (*Pisum sativum*) in the world. On average, Canada produces approximately 20% of world pea production and accounts for 50% of world pea exports. In 2003, Canada produced over 2.1 million metric tones of peas with over 70% of production occurring in Saskatchewan (FAOSTATS 2004). Approximately 35% of the peas produced in Canada are consumed domestically, with the largest use being livestock feed. The feed industry in many parts of the world recognizes the benefits of feeding peas as an alternative feed ingredient to traditional energy and protein sources like corn and soybean meal.

### *Nutritional Characteristics*

The average protein content (N x 6.25) of Canadian field peas is 23.0% with an especially high lysine content (1.67%), but deficient in sulfur-containing amino acids. Peas contain a moderate fibre level (crude fibre, 5.5%), with the fibre primarily associated with the seed coat (Vose et al. 1976). The energy fraction of the pea seed is comprised of starch which contributes almost 50% of the total seed weight. Pea starch differs from cereal starch in containing up to 34% amylose, and is generally considered to give a greater improvement in digestibility with heat treatment. In common with all plants, peas contain factors that act as natural defenses against pests; these include phytic acid (27-41% of total phosphorus, Marquardt and Bell 1988), condensed tannins, trypsin/chymotrypsin inhibitors, lectins and the antigenic proteins legumin and vicilin (Lalles and Jansman 1998, Orue et al. 1998). It is noteworthy that peas contain reduced

levels of these antinutritional factors relative to other pulse crops. Because of this, antinutritional factors in peas are thought to be of minimal nutritional significance – at least in terrestrial animals (Castell et al. 1996).

### *Processing*

Peas are routinely fed in an unprocessed form. However, further processing can be employed for specialized food and feed applications. Processing is an important consideration in the utilization of peas, or any other plant protein source, used in feeds for carnivorous aquatic species. Procedures range from simple dehulling to remove indigestible xylans and cellulose, to more advanced treatments such as fine grinding and air classification. Heat treatments, such as micronization, extrusion and expansion of ingredients, reduce antinutritional factor levels and alter the carbohydrate matrix, thereby increasing digestibility (Kaushik et al. 1993, Gomes et al. 1995, Orue et al. 1998).

Peas may be separated into their components (protein, starch and fibre) by dry or wet processing techniques, with the protein fraction being of particular interest for aqua feeds. In dry processing, fine grinding of dehulled peas produces pea flour with particles of various sizes and densities (Vose et al. 1976). Subsequent air classification separates the less dense protein fraction from the coarser starch fraction to produce a concentrated protein source containing approximately 56% protein. Some protein adheres to the starch granules, even with multiple fine grinding and air classification passes, resulting in two to five percent residual starch in the protein fraction (Vose et al. 1976, Tyler et al. 1981). Dry processing (air classification) of peas concentrates protease inhibitors, phytic acid (Owusu-Ansah and McCurdy 1991) and the  $\alpha$ -galactosides (Vose et al. 1976). Wet processing methods involve milling of peas followed by solubilization of the protein in water, alkali or acid washings (Vose 1980, Owusu-Ansah and McCurdy 1991). This method results in a more pure protein fraction, producing a pea protein concentrate (65-70% protein) or a pea isolate (90% protein). Negligible levels of antinutritional factors and starch remain in the protein isolate (Vose 1980).



### *Use in Aquafeeds*

Pea protein, regardless of processing, has been observed to be highly digestible in aquatic species. The observed apparent protein digestibility for raw peas in carnivorous species ranges from 81.9% to 91.4% in rainbow trout (Kaushik et al. 1993, Gomes et al. 1995, Pfeiffer et al. 1995, Thiessen et al. 2003) and 79.8% to 91.0% in shrimp (Smith et al. 1999, Cruz-Suarez et al. 2001); 91.0% in the omnivorous silver perch (Allan 1997); and 85.0% in the herbivorous tilapia (Borgeson et al. unpublished data). Digestibility of pea protein appears to be favorable, regardless of heat processing (Kaushik et al. 1993, Pfeiffer et al. 1995, Cruz-Suarez et al. 2001, Thiessen et al. 2003). The principal advantage of heat treatment with peas is matrix structure and starch granular disruption via gelatinization thereby allowing easier and more rapid attack of the swollen starch granule by amylases. Extrusion treatment of peas significantly increased starch, and consequently, energy and dry matter digestibility in rainbow trout from 0-96%, 29-72%, and 25-72%, respectively (Kaushik et al. 1993). Thiessen et al. (2003) found that extrusion of peas greatly increased digestibility of the starch fraction in trout, but this was not expressed in digestible energy to any large extent. Ingredient digestibility and performance was slightly enhanced in shrimp fed extruded peas (Cruz-Suarez et al. 2001).

Superior growth performance and nutrient utilization of blended protein sources is often attributed to the improved amino acid profile resulting from the complementarity of protein sources. Research with rainbow trout and European sea bass indicate that inclusion of 25 to 40% raw peas in the diet did not induce palatability problems, and performance and nutrient utilization were not adversely affected (Gouveia et al. 1993, Gouveia and Davies 1998, Thiessen et al. 2003). Likewise, inclusion of 25 to 40% of expanded or extruded peas in the diet resulted in significantly increased weight gain and specific growth rate and resulted in similar, or improved, feed conversion and feed intake relative to a fish meal reference diet and a commercial grower diet (Gouveia et al. 1991, Kaushik et al. 1993, Gouveia and Davies 2000). Shrimp readily accepted 30% pea meal

in the diet and performed similarly to shrimp fed diets containing common shrimp feed ingredients (Cruz-Suarez et al. 2001).

Removal of the fibrous hull of peas did not increase the digestibility of peas in rainbow trout or blue shrimp (Cruz-Suarez et al. 2001, Thiessen et al. 2003). However, air classification (concentrating the protein and removing the majority of the carbohydrate component of peas) produced a pea ingredient with superior protein, energy and dry matter digestibility in rainbow trout and in silver perch (Booth et al. 2001, Thiessen et al. 2003). Inclusion of 20% air classified pea protein in rainbow trout diets and up to 27% air classified pea protein in salmon diets resulted in high feed intake, desirable weight gain, and a favorable feed conversion (Carter and Hauler 2000, Thiessen et al. 2003). Wet processing methods may be used to obtain a highly purified pea protein fraction (77-85% crude protein content). The apparent crude protein digestibility of wet processed pea protein concentrates in rainbow trout was 97% with individual amino acid digestibility values confirming this value (Thiessen et al. unpublished data). An added benefit with the inclusion of pea products is their usefulness as a binding agent in producing stable pellets, particularly for high lipid formulations. Cruz-Suarez et al. (2001) noted that extruded whole peas produced a pellet with good water stability for blue shrimp.

## **Canola**

### *Production*

Canola (*Brassica campestris* or *Brassica napus*) refers to selected varieties of rapeseed that are low in glucosinolate (<30  $\mu$ moles of alkenyl glucosinolates per gram of oil-free dry matter of seed) and erucic acid (<2% of total fatty acids in the oil) (Bell 1993). On a world-wide basis, canola is second only to soy in terms of production of oilseed crops (FAOSTAT 2004). Canola grows best in temperate, moist climates. Canada is the second largest producer of canola in the world and the largest exporting country. Production in Canada last year was 6.7 mmt with Saskatchewan being by far the most significant canola growing province in the country. Approximately 50% of canola seed is processed

in Canada and the remainder exported. Processing involves crushing and solvent extracting the seed to remove the oil which is highly valued as a healthy alternative vegetable oil. The meal derived from canola seed is marketed as a feed ingredient to a wide range of animal species including poultry, swine and cattle. Canola makes up about 4% of world trade in protein meals (Agriculture and Agri-Food Canada 2004).

### *Nutritional Characteristics*

The typical protein content (N x 6.25) of canola meal is 35.0%. Canola protein is well established as having a very good balance of amino acids that is superior to other plant proteins and is considered a good source of the sulphur amino acids, methionine and cystine. Canola meal contains comparably high levels of crude fibre (12.0%) due to the fact that canola seed is not dehulled prior to oil extraction. In addition, the meal contains a complex carbohydrate structure comprised of sugars (8.0%), starch (5.2%) and non-starch polysaccharides (1.4% soluble NSP, 14.7% insoluble NSP)(Saskatchewan Canola Development Commission).

Canola meal contains a high level of phytic acid (4.0%; approximately 75% of total phosphorus) which is the storage form of phosphorus for plants and has been demonstrated to have antinutritional properties. Phenolic compounds, notably sinapine and tannins, also occur in canola products. Sinapine (1.0%) has a bitter flavour and may decrease palatability if canola products are included at high levels, particularly in young animals (Bell 1993). The hydrolytic products of glucosinolates can cause meal quality problems and can impact thyroid function, feed acceptance and liver and kidney function (Campbell and Schone 1998, Cheeke 1998). There has, however, been a continued lowering of glucosinolate levels in canola meal through plant breeding. On average, canola meal contains 16 µmoles per gram of total aliphatic glucosinolates (oil free basis) compared to 120-150 µmoles per gram of aliphatic glucosinolates in cultivars of rapeseed.

Canola meal is a widely accepted ingredient in livestock diets. Inclusion levels are typically restricted in very young animals primarily due to the fibre level and the negative effect of tannins, glucosinolates and sinapine on feed acceptance. However canola meal can be effectively used as the major supplemental protein source in grower rations for livestock.

### *Processing*

A reduction in the high content of hulls and indigestible polysaccharides in conventional canola meal has been a primary target for improvement by processing. Simple sieving procedures remove coarse fibrous particles thereby significantly decreasing the fibre level by 32-50% and concurrently increasing the protein content (McCurdy and March 1992, Mwachireya et al. 1999, Thiessen et al. 2003). Solvent washing of canola meal is effective in removing glucosinolates, phenolic compounds and oligosaccharides and concentrating protein; phytic acid levels are concentrated (McCurdy and March 1992, Mwachireya et al. 1999). Phytase has been successfully used to reduce phytic acid levels in the canola ingredient and in the finished diet (Teskeredzic et al. 1995, Forster et al. 1999, Mwachireya et al. 1999). Despite having an exceptionally favorable amino acid balance, conventional canola meal processing has been shown to be the cause of variable and low digestible amino acid levels leading to recommendations that commercial systems be modified to produce a non-toasted meal that would contain higher levels of digestible amino acids and be of more consistent quality (Newkirk et al. 2003).

Canola protein concentrates (>60% crude protein) and protein isolates (>90% crude protein) are prepared by extraction of canola meal with an aqueous salt solution. These canola products contain very low levels of antinutritional factors with the exception of an elevated phytic acid level (Higgs et al. 1994, Higgs et al. 1995a, Mwachireya et al. 1999). A completely dephytinized canola protein concentrate has been developed that offers a high quality source of protein and an effective means to control phosphorus and nitrogen emissions from intensive farming operations (Maenz 2002, Classen et al. 2004).





### *Use in Aquafeeds*

An extensive review of canola product use in finfish diets is available (Higgs et al. 1995). Research on the digestibility of canola protein in rainbow trout has showed a marked improvement in protein and energy digestibility with processing treatments to reduce levels of fibre, glucosinolates, sinapine, phytate and carbohydrate and to concurrently increase the protein content (McCurdy and March 1992, Hagen et al. 1993, Higgs et al. 1995, Mwachireya et al. 1999, Thiessen et al. 2004). Apparent protein digestibility values exceeding 95% for canola protein concentrate fed to Chinook salmon in seawater and canola protein isolate fed to rainbow trout, in addition to individual amino acid digestibility of canola protein concentrate ranging from 87-95%, indicate that the protein fraction of concentrated canola protein products is highly available to salmonid fish (Higgs et al. 1994, Mwachireya et al. 1999, Thiessen et al. 2004). The energy digestibility of canola protein concentrate in rainbow trout is higher than values reported for other vegetable protein meals, concentrates and isolates, but lower than of fish meal (Thiessen et al. 2004).

Early research showed that canola meal could be included at levels up to 20% of the diet of trout without affecting performance and end product quality (Hardy and Sullivan 1983). Utilization of fibre-reduced, acid washed canola meal as 40% of dietary protein for trout (6g) resulted in superior performance relative to commercial canola meal (McCurdy and March 1992) whereas fibre-reduced canola meal did not have improved nutritive value for shrimp (Lim et al. 1997). Very favorable nutrient digestibility and performance parameters have been also been obtained with the use of canola meal in the diets of silver perch (Booth and Allan 2001), catfish (Webster et al. 1997) and abalone (Sales and Britz 2003).

Results indicate that canola protein concentrate has comparable nutritive value to fish meal, with canola protein being able to supply 59-71% of dietary protein without adversely affecting feed intake, growth rate, feed efficiency and protein utilization in

salmonid fish (Forster et al. 1999, Thiessen et al. 2004). Similarly, canola protein will combine well with other protein sources in complex diet formulations, typical of commercial-like formulations, to maintain fish/shrimp performance (Teskeredzic et al. 1995, Lim et al, 1997, Cruz-Suarez et al. 2001, Thiessen et al. 2004).

## **Flaxseed**

### *Production*

A record of flaxseed (*Linum usitatissimum*), or linseed, origin extends to the beginnings of human agriculture. It is thought that flaxseed cultivation began in Southern Mesopotamia as early as 5000 BC. The growth of flaxseed as a crop spread from Europe to Africa, Asia and into North America. Canada is the world's largest producer and exporter of flaxseed. Production in Canada in 2003 was 754,000 mt with Saskatchewan producing approximately 65% of total flaxseed production (FAOSTAT 2004). Today, the majority of Canadian flaxseed is exported to the EU where the seed is crushed to produce linseed oil used for many industrial purposes.

There is great interest in the health benefits of flaxseed in human diets. Ancient people valued flaxseed for its medicinal properties, its oil for cosmetics, and its fibre for making linens and cloth. Recent research has revolved around the health benefits of omega-3 fatty acids and the nutraceutical benefits of flaxseed. As such, flaxseed can be included into livestock rations to modify the fatty acid composition of meat, milk and eggs thereby providing additional health benefits to consumers.

### *Nutritional Characteristics*

Flaxseed is rich in lipid and dietary fibre. The typical composition of Canadian flaxseed averages 41% lipid, 28% total dietary fibre and 20% protein (Flax Council of Canada). Flaxseed has a unique fatty acid profile; more than half of the lipid in flaxseed is of the

omega-3 family with the majority of the polyunsaturated fatty acids being  $\alpha$ -linolenic acid. Flaxseed is one of the richest sources of  $\alpha$ -linolenic acid.

Also of interest is the fibre component of whole flaxseed. The true hull is called the spermoderm or testa and is covered on the outside by the epiderm, containing mucilage which gives the flaxseed a high shine. The inside of the hull is covered by the endosperm. The fibre content of flaxseed, which is approximately 30-39% of the seed weight, is derived from the mucilage, the hull layer and the cell walls of the endosperm and cotyledons (Freeman 1995). This mix of fibre is what makes flaxseed unique from other whole grains, containing generous quantities of both soluble and insoluble fibre.

The protein content of whole flaxseed can be variable (23-34%), with a negative correlation existing between the oil and protein content (Bhatty 1995). This variability has been primarily attributed to environmental conditions. Canadian grown flaxseed contains on average 26% crude protein (N X6.25) with a favorable amino acid profile that is similar to soy flour (Bhatty 1995). The first limiting amino acid is lysine.

### *Processing*

The usefulness of flaxseed as an energy dense ingredient in monogastric diets has been hampered by the level of soluble fibre which increases gastric viscosity and leads to reduced nutrient availability (Bell and Keith 1993). There have been many attempts at removing the hull of flaxseed. These can be broken down into dry and wet processing techniques.

Abrasive dehulling has been used to gradually grind or rip the hull of the seed off (Oomah et al. 1996). Other methods have involved finely grinding whole flaxseed and then sieving and aspirating to separate hull material from cotyledons (Oomah et al. 1997). Wet processing methods have included simple hot water extraction procedures where a certain weight/volume ratio of seed and water is used (Cui et al. 1994); enzymatic

degradation of linseed mucilage using polysaccharide degrading enzymes which leave the testa intact (Wanasundara and Shahidi 1997); and chemical dehulling procedures that peel the outer layers of the hull off with various chemicals and strong alkali (Wanasundara and Shahidi 1997).

#### *Use in Aquafeeds*

We recently examined the effect of feeding whole flaxseed and hot water extracted whole flax seed (HWE Flax) to rainbow trout. A basal diet containing 45% fishmeal and 12% fish oil was used as a control. The test diets contained 12% whole flaxseed or 12% HWE flaxseed combined with 41% fishmeal and 5% fish oil. The results are shown in Table 1. The fish receiving 12% HWE flax had significantly higher weight gains than those receiving whole flaxseed. Feed efficiency of the controls and HWE flax fed fish was not significantly different ( $P > 0.05$ ). The results demonstrate that moderate levels of flax with the mucilage extracted can replace more than 50% of fish oil in the diet with no decrease in growth performance.

Table 1. Performance of rainbow trout fed diets containing 12% whole flax or hot water extracted (HWE) flax for a 7 week period.

Diet	Average Daily Gain (g/d)	Average Daily Feed Intake (g/d)	Feed:Gain (g:g)
Control	0.76 <sup>a</sup>	0.75 <sup>ab</sup>	0.99 <sup>a</sup>
12% Flax	0.62 <sup>b</sup>	0.69 <sup>b</sup>	1.12 <sup>b</sup>
12% HWE Flax	0.79 <sup>a</sup>	0.81 <sup>a</sup>	1.03 <sup>a</sup>

<sup>ab</sup>Means with different superscripts are significantly different ( $P < 0.05$ ).

Extrusion of whole seed oilseeds with other protein sources creates valuable ingredients for the feed industry. The co-extrusion of whole seed rapeseed with pea products (Colzapro) created a protein source with an amino acid profile rich in lysine and methionine, and an ingredient with high energy due to its high lipid content (Gomes and Kaushik 1989). Inclusion of this product in trout diets, at 15% of dietary protein, resulted in similar apparent nutrient digestibility to a fish meal diet. Increasing the inclusion level of this product to 45% of dietary protein resulted in decreased nutrient digestibility, attributed to the higher fibre level in the diet (Gomes et al. 1993).

We recently conducted a performance experiment to test the hypothesis that dehulled flaxseed co-extruded with pea protein or canola protein concentrate produced viable ingredients for salmonid fish (Thiessen, unpublished data). A dry dehulling method separated the hulls and cotyledons from wholeseed flax resulting in a low mucilage flaxseed product (DF). DF was blended in 1:1 with pea protein concentrate (PPC) (Propulse 975: Parrheim Foods, Portage la Prairie, MB) or canola protein concentrate (CPC) (CanPro; MCN BioProducts Inc., Saskatoon, SK), preconditioned and extruded (Table 2). The DP: PPC and DF: CPC ingredients were incorporated into diets at two levels (40, 60-75%), and fed to quadruplet groups of rainbow trout for nine weeks, alongside a fish meal/fish oil control diet (Table 3). DF: PPC and DF: CPC proved to be high protein, high energy ingredients that are highly digestible and palatable to juvenile rainbow trout. Inclusion of 40% DF: PPC allowed the reduction of 47% of the fish meal and 55% of the fish oil component of the diet with favorable weight gain and feed efficiency (Table 4). Likewise, inclusion of up to 60% DF: CPC allowed the reduction of 62% of the fish meal component of the diet with favorable performance (Table 4).

Table 2. Nutrient analysis of Pea Protein and Canola Protein Products and Coextruded Dehulled

Flaxseed: Protein Products (%)				
	PPC	CPC	Dehulled Flax:PPC	Dehulled Flax:CPC
Dry matter	90.7	90.8	94.8	91.3
Gross energy (Kcal kg <sup>-1</sup> ) <sup>a</sup>	5349.1	4775.8	6093.2	6037.8
Crude protein <sup>a</sup>	76.9	69.5	46.7	48.1

<sup>a</sup>Dry matter basis

Table 3. Fish meal control and dehulled flax:plant protein diet formulations

	Fish meal reference	40% PPC	75% PPC	40% CPC	60% CPC
<i>Ingredient inclusion (g/kg)</i>					
Fish meal	590	310	95	345	225
Wheat flour	265	218	130	105	20
DF:PPC	-	400	750	-	-
DF:CPC	-	-	-	40	60
Fish oil	135	60	10	140	145
Vit/min premix	10	12	15	10	10
<i>Nutrient composition</i>					
DP:DE (g/MJ)	23.4	23.5	23.5	23.5	23.5



Table 4. The performance of rainbow trout fed dehulled flax: plant protein as a protein and lipid source

	<b>Fish meal reference</b>	<b>40% PPC</b>	<b>75% PPC</b>	<b>40% CPC</b>	<b>60% CPC</b>	<b>SEM</b>
Mean fish weight (g/fish)	559.83 <sup>a</sup>	466.18 <sup>b</sup>	342.95 <sup>c</sup>	521.55 <sup>a</sup>	452.45 <sup>b</sup>	16.92
Weight gain (g/fish)	296.83 <sup>a</sup>	221.03 <sup>b</sup>	95.23 <sup>c</sup>	257.70 <sup>ab</sup>	226.10 <sup>b</sup>	13.19
Feed intake (g/fish)	369.68 <sup>a</sup>	311.83 <sup>b</sup>	233.53 <sup>c</sup>	368.18 <sup>a</sup>	303.70 <sup>b</sup>	12.86
FCR <sup>1</sup>	1.26 <sup>b</sup>	1.41 <sup>b</sup>	2.50 <sup>a</sup>	1.44 <sup>b</sup>	1.35 <sup>b</sup>	0.13
SGR <sup>2</sup> (5)	1.27 <sup>a</sup>	1.09 <sup>b</sup>	0.56 <sup>c</sup>	1.14 <sup>ab</sup>	1.16 <sup>ab</sup>	0.043

<sup>1</sup>FCR= Feed conversion ratio = dry feed intake/wet weight gain. <sup>2</sup>SGR= (ln final weight/ln initial weight)/time (days) x 100.

<sup>abcd</sup>Means in the same row with different superscripts are different (P< 0.05).

Both products appear to be promising new feed ingredients for the aquaculture industry. Since the supply of fishmeal and fish oil is a major constraint on the growth of the aquaculture feed industry, the use of co-extruded flaxseed: plant protein ingredients provides long term sustainability to the industry.

## Conclusion

Results from an increasing number of studies clearly indicate that plant proteins and oilseed lipids can be very valuable ingredients for fish feed formulation. Overall, the use of these bountiful, lower-cost alternatives to fish meal and fish oil could result in immediate and very significant savings in feed costs without compromising fish performance and end-product quality.

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