



# BIOFUEL CO-PRODUCTS AS LIVESTOCK FEED

Opportunities and challenges

*Technical Summary*



**Recommended citation**

**FAO.** 2014. *Biofuel co-products as livestock feed - Opportunities and challenges, Technical Summary* by Harinder P.S. Makkar. Rome.

**Author**

**Harinder P.S. Makkar**

Livestock Production Systems Branch  
Animal Production and Health Division  
FAO, Rome, Italy  
Harinder.Makkar@fao.org

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# Technical Summary

## INTRODUCTION

Distillers grains (DG), a by-product of the alcoholic drink and beverages production, have been fed to livestock for several years, initially to pigs and dairy cows. The upsurge in the use of DG was spearheaded by the search for transport fuel other than that from fossil fuels, which in recent years has been supported by a large increase in research funding into the use of co-products. The co-products are the residues after extraction of the biofuel – ethanol or biodiesel. Currently, these co-products are an important feed resource in over 50 countries, for ruminants, non-ruminants and fish. Biofuels contribute to the twin objectives of increasing fuel security and as a tool in the reduction of emissions of green house gases (GHG). As the majority of currently used feedstocks to produce biofuels are crops grown on agricultural land, the requirements for food, feed and fuel must be balanced so that the quest for biofuels does not result in an inflationary rise in the cost, or shortage, of food or feed. This raises the question of second generation feedstocks from cellulosic sources, the use of crop residues and stubbles and woody material grown on marginal land with a minimum of resources, including irrigation. Also it raises the potential for promoting little-used feeds, from non-conventional feedstocks, of which some may require detoxifying to produce safe livestock feed.

The co-products produced by the biofuel industry are discussed below in two main headings: a) produced along with the ethanol production, and b) produced along with the biodiesel production.

## FEEDSTOCKS FOR ETHANOL PRODUCTION

### Cereal feedstocks

In the United States of America (USA) corn, or maize is the dominant source. The USA has also built an export trade in dried distillers grains with added solubles (DDGS), initially to Canada for beef production, but now expanded to a wider market with an emphasis on pig and poultry production. In the Southern Great plains of the USA sorghum is an important feedstock, thus giving rise to considerable quantities of co-products based on this cereal. In Canada the major cereal contributing to the industry is wheat. In Europe the dominant feedstock for ethanol production is also wheat, although some other cereals, especially barley may be added to the mix. Rye is also used as a feedstock, but is restricted to colder areas.

### Sugar cane and other non-cereal feedstocks

Sugar cane is also a major feedstock for ethanol production. On a global scale 90% of ethanol output is accounted for by corn and sugar cane. Other feedstocks include tropical sugar beet, sweet potato, cassava, and sweet sorghum.

## ETHANOL CO-PRODUCTS

Globally there are now approximately 200 plants producing 3.5 million tonnes of co-products annually. Ethanol production is estimated at 51 billion litres in 2010, over three times as much as in 2005, with 32.9 million tonnes of distillers grains being produced, of which 2.7% came from the beverages industry. Currently, in the USA, the beef industry uses 66% of the available distillers grains, the dairy industry 14%, pigs 12% and poultry 8%, and there has been little evidence of meaningful amounts being used in aquaculture. However, due to the high price of the traditional protein sources, fishmeal and soya bean meal, and the comparatively low price of DDGS, its use is expected to increase. In Western Canada the current demand for DDGS is estimated at 1.4 million tonnes but the local industry, based on wheat, can only produce around half a million tonnes, the shortfall being met from the USA. Important co-products obtained during ethanol production from sugarcane and sweet sorghum are bagasse and vinasse.

## NUTRITIVE VALUE OF ETHANOL CO-PRODUCTS FOR LIVESTOCK

### Ruminants

Distillers grains are regarded as a cost effective energy feed that also contain substantial amounts of crude protein (CP) with useful amounts of amino acids (although supplementary lysine may need adding for high yielding dairy cows and poultry production) and are also rich in digestible phosphorus (P) compared to other feeds. Because the process of producing ethanol reduces the energy content, but not the fibre content, of the residue, distillers grains are higher in fibre than the whole grain from which they originated, although roughage should still be included in the diet because of the fineness of the fibre particles of that coming from the grains. There is also evidence that the rumen degradability of crude protein is reduced but this can be ignored if the distillers grains (DG) does not exceed 30% of the diet, at which point some supplementary urea may be necessary.

The corn co-products are seen primarily as a source of dietary protein in feedlot diets although at high levels of inclusion, when they replace substantial amounts of whole grain, the fat and fibre will contribute meaningful amounts of energy. The corn gluten feed (a product of wet milling) and distillers grains with added solubles (DGS) have a low starch content, thus removing the negative effects of diets containing large amounts of whole grain on fibre digestibility, and also reducing the acidosis challenge of grain-rich feedlot diets.

Some authors rated the feeding value of DDGS at approximately 1.2 of that of corn, the reduction of energy



during the extraction process having increased the percentage contribution of the protein fraction. At up to 40% of the diet, modified and dry DDGS can have a feeding value up to 30% greater than corn, although the difference narrows at inclusion rates above 40%. However, if the level of S exceeds 0.47%, which is the recommended level of dietary inclusion, performance can be reduced and in some cases polioencephalomalacia (a disorder of the nervous system) can occur.

In Germany wheat-based DDGS have successfully replaced traditional protein sources in dairy cows at up to 200 g per day and can also be used as the main dietary protein source for fattening cattle. However, DDGS may be from a mixture of feedstocks, which will have a bearing on their nutritive value. Distillers grains from barley is rated as the least productive cereal feedstock, because of the relatively high fibre and low starch content of the grain. Studies have been conducted wherein diets containing 40% of DDGS were successfully incorporated in feedlot diets and although the product could be produced through a wet milling plant the expense of drying could in some circumstances be justified by ease of transport and a longer shelf life. Wet products such as wet distillers grains contain 23–24% solids and thin stillage (liquid residue after removal of the grains) containing 8.5% solids. Condensed distillers solubles (CDS) result from evaporation of the stillage and can be added to either wet or dry DG to give wet distillers grains with added solubles (WDGS) or DDGS.

For lactating cows, WDGS from maize is judged a good source of undegradable (bypass) protein when fed at up to 30% of the diet, although peak response will probably be around 21%. Supplementation with lysine may be necessary for which a check on the amino acid profile of the milk will indicate if this is so. For dairy heifers, where restricted growth is often desirable to encourage development of mammary tissue, feeding WDGS will allow use of poorer quality forages, examples being soya bean or corn stalks. For dry cows there is little direct information, but a similar feeding regime to that of growing heifers is probably adequate, although a 15% supplement of WDGS during the last four weeks of pregnancy has been found to improve energy balance and resistance to ketosis in early lactation. With calves 25–30% of the maize can be replaced with DGS if the rumen is fully functional, but lysine and methionine levels should be checked.

The value of DDGS produced from both wheat and other sources will depend on the original feedstock although the method of processing is the dominant factor, with colour indicating the degree of heating involved. After removal of the starch for ethanol other components of the grain residue, such as fat, fibre and protein are approximately three times as concentrated as in the original crop, although levels of the essential amino acids, lysine and arginine will

be reduced. It is suggested that processing should receive attention to assure a high quality uniform product capable of diversification to allow more specification.

Sugar cane bagasse is fibrous and of low nutrient density and must be supplemented to support maintenance. The amount of bagasse to be incorporated in ruminant diets will depend on the level of production expected, with a range of 30–40% in the diet for medium levels of production and up to 60% for low level production. Supplements for use with bagasse will be those suitable for mixing with any low grade forage including urea, molasses and locally available concentrates. Co-products from sweet sorghum, the vinasse can be used to prepare multi-nutrient blocks.

### Non-ruminants

A shift from the traditional use of DDGS as a substitute for the higher priced corn and soya bean in cattle diets towards pigs, poultry and fish has been recorded, although the optimum levels of inclusion are still being determined. Distillers grains with solubles or with added protein (HP-DDGS) can be fed to pigs at all stages of the production chain. The energy of DDGS is similar to corn, unless the oil has been removed, but the energy of HP-DDGS is higher. The digestibility of P in DDGS is high. Growing pigs, from two to three weeks after weaning can be fed diets containing 30% DDGS (gestating sows 50%) as long as all amino acid requirements are met. With finishers it may be necessary to withdraw DDGS three to four weeks before slaughter because the higher iodine content could reduce fat quality. Diets for lactating sows can contain 30% DDGS, thus replacing all the soya bean in the diet.

It has been observed that DDGS up to 20% of the diet of pigs did not affect growth, fattening and carcass composition. With laying hens, inclusion levels between 15 and 30% DDGS had no effect on laying intensity, egg quality and hen health, but with broilers there was a suggestion that levels above 10% may reduce performance unless non-polysaccharide degrading enzymes are added to the diet.

Wheat DDGS are seen as sources of energy, protein and P for poultry and pigs. Crude protein of DDGS can be as high as 30%, but lysine levels are low and variable, with ileal digestibility lower than with whole wheat especially if the DDGS has any heat damage; the energy value of wheat DDGS is also lower than whole wheat, the difference being dependent on the fibre content of the DDGS; however, wheat DDGS can be included at up to 30% in poultry and pig diets as long as the diet meets the criteria for the desired output. Whereas with ruminants H<sub>2</sub>S can be a major problem, in non-ruminants H<sub>2</sub>S formed in the gastrointestinal tract is largely excreted or absorbed and detoxified in the liver although there may be a link between inorganic S and chronic intestinal disease.

## Fish

Fish have requirements for specific amino acids (AA) and although DDGS has a similar AA profile to corn it is deficient in lysine. Differences between species of fish should also be noted. Diets can be balanced, either by including DDGS in a cocktail of protein feeds or by the addition of synthetic AA. DDGS is rich in vitamins and P but is short of Ca, Cl and trace minerals. Currently only DDGS from maize, and of the new products available only high protein DDGS (HP-DDGS), have been tested for use in aquaculture (the use of barley is limited because of its high content of beta-glucans). Growth, feed utilization and flesh composition in eight species of fish, Nile, hybrid and red tilapia, channel catfish, rainbow trout, yellow perch, common carp, freshwater prawn, pacific white shrimp, re claw crayfish and sunshine bass, are summarised in Table 5 of Chapter 23 of the FAO document listed below. The species requiring supplementary lysine if DDGS exceeds 30% of the diet are tilapia and channel catfish. Feed efficiency in rainbow trout is reduced if DDGS is included in the diet. There are indications that the digestibility of DDGS is lower than that of soya bean meal or fishmeal, thus indicating that more of the feed is excreted into the pond thereby becoming a possible source of pond pollution.

## FEEDSTOCKS FOR BIODIESEL PRODUCTION

In 2010 a total of 140 plants produced 1.2 billion litres of diesel. Europe is the world leader in biodiesel production from vegetable oils although currently rape seed supported by imported soya bean meal is the backbone of the industry. In the USA soya bean is the major feedstock for biodiesel. The importance of the oil palm industry to the Malaysian economy cannot be understated with palm oil and palm kernel oil in 2008 being 30% of total global production from 4.498 million hectares of land. There are also potentially productive sources of biodiesel but for their residues to contribute fully as livestock feed detoxification is required, examples being *Jatropha* and Castor (Table 1).

*Camelina sativa*, also known as false flax is an oil seed crop of the brassica family. For over 2000 years it has been cultivated in Europe for its oil and as a livestock fodder. It survives well on marginal land, needs very few inputs and no irrigation, thereby keeping conflict for scarce resources of land, water and fertilizer at a minimum. *Pongamia pinnata* are low rainfall oilseed crops. With the increased use of algae for oil production, research into technical aspects of using these sources is needed. Currently there is no commercial activity with algae.

## BIODIESEL CO-PRODUCTS

The two major co-products from the biodiesel process are protein-rich cakes/meals and glycerol. In the USA in 2010, 48% of glycerol was sold for high value uses, while 33%

went to the livestock feed industry. Mature cattle can consume one kg of glycerine per day, as a source of rapidly fermentable carbohydrate. Glycerine also has humectant properties beneficial in both food and feed production systems, in the latter for texturing properties and dust control, although reduced production costs of pellets and improved hygiene have also been noted.

Camelina meal contains 36–40% crude protein and 11–12% fat. Its protein is rich in essential amino acids including lysine and methionine. The fat is rich in alpha-linolenic acid, parent fatty acid of omega-3 and the antioxidant tocopherol, both necessary for healthy productive poultry and quality poultry products for humans. Castor cake is a high protein product but its use as livestock feed is restricted because of toxins, especially ricin. Castor cake could be as a major source of protein for livestock in major producing countries such as China, India and Brazil.

## NUTRITIVE VALUE OF BIODIESEL CO-PRODUCTS

### Ruminants

The cakes and meals have long been major sources of crude protein in commercial livestock and poultry production, the market being dominated by soya bean. Glycerol, a glucose precursor, has traditionally been used as a drench for dairy cows to combat ketosis, often shortly after calving, because it is rapidly fermentable within the rumen, favouring a butyrate fermentation pattern. However, it can also be used as a supplement for transition cows, or as a replacement for maize at 10–12% of the diet, but it should be noted that its effect in causing a reduction in fibre digestibility is similar to that of a supplement of starch. Adding glycerine to the diet will favour a propionate/butyrate, rather than acetic, rumen fermentation, although this may be affected by the level of glycerine and the composition of the rumen flora.

In Europe rapeseed products are widely used in cattle, pig and poultry diets. Recommendations from Germany are available for daily amounts of both rapeseed meal (solvent extracted) and rapeseed cake (mechanically extracted), which range from 4 kg of rapeseed meal for a dairy cow (2 kg of rapeseed cake) to 0–100 g of the meal and 50–100 g of the cake for laying hens. Rapeseed meal can completely replace soybean meal in dairy cow rations although there may be differences in intake of energy, rumen degradability and amino acid profiles between the two sources.

The two major by-products from palm oil processing are palm kernel cake (PKC), also known as palm kernel expeller (PKE), and crude palm oil (CPO). Expeller palm kernel meal (PKM) has a substantially higher oil content than the solvent extracted material and the amino acid profile shows deficiencies in lysine, methionine and tryptophan. The Malaysian palm oil industry also produces valuable by-products resulting directly from the field operations. These include oil palm fronds (OPF) from pruning,

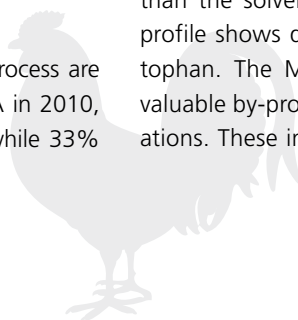


TABLE 1  
Feedstocks used for biodiesel production, their co-products and major areas of utilization

Feedstock	Co-product	Co-product utilization by livestock
Soya bean (3) Rapeseed (11) Vegetable oils (2) Corn oil (27)	Crude glycerine (3, 8, 7, 23); several uses, human foods/ pharmaceuticals/commercial etc. (8) Oil seed cake (mechanically extracted) and meal (solvent extracted); methanol should be removed (11)	Pigs (3, 10) Beef cattle (8) Fish (23) Dairy, beef, pigs and poultry (11) Glycerol as drench and supplement for dairy cattle (7)
Camelina sativa (17)	Camelina meal: derives from member of the brassica family that grows on marginal land, no irrigation needed. Meal is rich in amino acids and antioxidants (17)	Poultry (broilers and layers) (17)
Jatropha (20, 21)	Heated <i>J. platyphylla</i> kernel meal (21) Detoxified <i>J. curcas</i> kernel meal and detoxified protein isolate (21) Heated kernel meal from non-toxic genotype of <i>J. curcas</i> (21)	Fish, turkeys and pigs (21)
Oil-palm (13, 14) Oil palm ( <i>Elaeis guineensis</i> ) and babussa ( <i>Oribgnya phalerata</i> ) (14)	Rapidly expanding industry with several by-products from refining of crude palm oil (CPO) or palm kernel oil (PKO); oil palm fronds, trunks, press fibre, empty fruit bunches, kernel cake and oil mill effluent-products available in the field and ex-processing (also solubles)/aim is integration of livestock industry with oil palm production (13) Oil palm and babussa oil used for food, charcoal, soap and now biodiesel (14)	Ruminant feeding/complete diets based on oil palm, poultry/pigs and fresh water fish (13) Oil palm and babussa feed for collared peccary (pecari tajacu) (14)
Seed oils (18)	Co-products derived during bioethanol and biodiesel production (18)	In livestock feed as feed additives (but also used in human food and cosmetics) (18)
Microalgae (24, 25)	Algae residues left after extraction of oil (24)	Fuel, food, feed and chemicals (24)
Brassica juncea (25)	Juncea meal (residue after oil extraction, 25)	Juncea meal (Pigs, 25)
Pongamia pinnata (25, 19)	Pongamia pinnata meal (residue after oil extraction, 19, 25)	Pongamia pinnata meal at low levels as livestock feed (25) (possible toxicity problems, 19)
Pongamia glabra (22)	Pongamia glabra meal (Karanj seed cake) – de-oiling needed for complete detoxification (22)	Karanj and neem seed cakes after treatment fed to ruminants and poultry (22)
Azadirachta indica (22, 19)	Azadirachta indica (neem seed cake) – water washing reduces toxicity (19, 22)	
Non-edible oils (19)	Oil cakes and meals; detoxification needed; the following meals can be fed after treatment: <i>Ricinus communis</i> ; <i>Hevea brasiliensis</i> (livestock trials needed); <i>Crambe abyssinica</i> ; <i>Azadirachta indica</i> ; <i>Pongamia pinnata</i> (19)	Ruminants used where oil cakes and meals were tested (19)
<i>Ricinus communis</i> (castor) (20)		<i>Jatropha</i> requires testing (21)
<i>Jatropha</i> (21)	Need for industrial/commercial uptake of detoxifying techniques for castor (6) With <i>Jatropha</i> removal of phorbol esters necessary (21)	

\* numbers denote chapter number in the FAO document (see Reference section).

felling and harvesting that are available throughout the year. The fronds can be chopped and fed fresh, which is the common practice, ensiled or processed for cubing or pelleting. Freshly chopped OPF is a common source of forage and can be fed at 40% of the diet, often with some added PKC to buffalo, cattle and sheep. If ensiled, the diet will benefit from a urea supplement to offset the low level of CP in the silage. The second field residue is oil palm trunks (OPT). The trunks can be chipped and ensiled and with added urea have a similar nutritive value to that of rice straw, the parenchyma being an excellent source of roughage for beef cattle. For beef and dairy cattle a pelleted ration is often used at about 30% of the diet. With beef cattle a maximum inclusion of 85% PKC is recommended, and for dairy cows 30–50% PKC. However, with sheep 30% PKC should be regarded as the maximum because of the Cu content of the cake, which can cause long-term

problems in this species. Both karanj and neem seed cake properly detoxified could replace 50% of the nitrogen in the diets of lambs.

### Non-ruminants

Crude glycerine contains more energy than corn for pigs. If affordable, sow diets can contain up to 9% and weaners at least 6% glycerine, which can be increased to 15% for finishers. Inclusion of glycerol in a mechanised system can assist with feed flow but amounts of Na and methanol (toxic) in the diet should be checked.

In poultry diets, camelina meal could be incorporated at 10% in layer and broiler diets without affecting the performance of the birds or quality of the products, and with a reduction in the omega-6:omega-3 ratio in meat and eggs. Castor cake, after treatment to detoxify the ricin, has been fed successfully to poultry but because of its high

concentrations of fibre and lignin is more likely to be better used by ruminants. Pigs fed *Brassica juncea* cake at up to 18% of the diet exhibited no ill effects, although at higher levels intake, and therefore growth rate, declined. Rape seed meal is lower in lysine than soya bean, and the crude protein is less digestible than soya bean meal, but it contains more of the sulphur bearing amino acids. Rape seed products are not commonly used in poultry diets and where they are used supplementary iodine may be necessary.

Only limited amounts of PKC can be fed to poultry because of its high crude fibre content and the presence of polysaccharides and shells. The recommendations are for a maximum of 20% PKC in the diet for broiler chicks and 20–25% for layers, and for muscovy ducks 30%. Pigs, both growers and finishers, are often fed 20–25% of the diet as PKC.

### Fish

With fish, the amount of PKC in the diet will depend on the species, current inclusion levels ranging from 30% for catfish and 20% for tilapia. However, work in progress involving treatment with enzymes indicate that the levels of PKC could be increased, thus allowing a reduction in the amounts of imported maize in the diet.

Detoxified *Jatropha curcas* kernel meal, *J. platyphylla* (a non-toxic *Jatropha* species) kernel meal and detoxified *J. curcas* protein isolate can replace 50, 62.5 and 75% fish meal protein respectively in fish diets without compromising their growth performance, nutrient utilization and health indicators. A non-toxic genotype of *J. curcas* is also available in Mexico, the heated kernel meal of this genotype is also an excellent feed resource. These are also good feed resources for poultry, pigs and ruminants. Since *Jatropha* meals are rich in phytate, addition of phytase in the diets of monogastric animals is necessary for effective utilization of the meals.

Trials with channel catfish and rainbow trout have shown that glycerol can be added to the diet at 10–12% and acts as a precursor for gluconeogenesis but not lipogenesis; however, although rainbow trout do not use glycerol efficiently as an energy source.

### Micro-algae

Micro-algae are rich in proteins and vitamins, therefore useful for food and feed. They also contain chemicals, pigments, fatty acids, sterols and polysaccharides. Algae thrive under a wide range of extreme conditions, have simple nutrient needs and a very fast growth rate, with the ability to accumulate fat up to 50% of their biomass. Algae yield biofuels (diesel) by trans-esterification of algal lipids or hydrocracking, i.e. cracking and hydrogenation of biomass containing hydrocarbons. Ethanol can be released from either algal biomass or algal cake. Many micro-algae con-

tain vitamin B<sub>12</sub> and some brown algae contain tocopherol. Micro-algae containing astaxanthin are also used as feed in aquaculture production, where they can be fed with, or replace fishmeal, acting as colouring agents in such species as salmon, rainbow trout and koi carp, as well as improving growth rate and survival; improved yolk colour and growth and survival have also been recorded in poultry. Micro-algae have also been fed to ruminants and pigs: they are a good source of carbohydrates and some contain cellulose, usable by ruminants. They tend to be deficient in the S containing amino acids, cysteine and methionine.

### KNOWLEDGE GAPS AND FUTURE RESEARCH NEEDS

The biofuels industry has evolved rapidly over the last two or three decades with developments in processing techniques and an expansion of the range of plants and other natural energy sources being considered as feedstocks. Much of the potential research identified as needed is concerned with co-product feeding value, the need for standardisation of products from within an individual plant and between plants, and the search for new feedstocks, particularly those indigenous to an area but underutilized, and safety standards (including detoxification of seed meals where necessary). Coupled with this is the need to consider the species to which the co-product is to be fed. Details on researchable issues can be obtained from Chapter 28 of the FAO document (see Reference section). In this Chapter Table 4 concentrates on distillers grains, including some of the potential constraints to their use. Table 5 brings together suggestions for investigating co-products from feedstocks other than those from cereals, including micro-algae. Table 6 presents the areas that don't belong in Tables 4 and 5, but all of which have relevance if the co-products industry is to remain economically viable and to benefit all sectors of the livestock industry.

### REFERENCE

FAO. 2012. Biofuel co-products as livestock feed: Opportunities and challenges, edited by Harinder P.S. Makkar, Rome, Italy (available at: <http://www.fao.org/docrep/016/i3009e/i3009e00.htm>)

### ACKNOWLEDGEMENT

The author thanks all contributors to the FAO document listed above.

