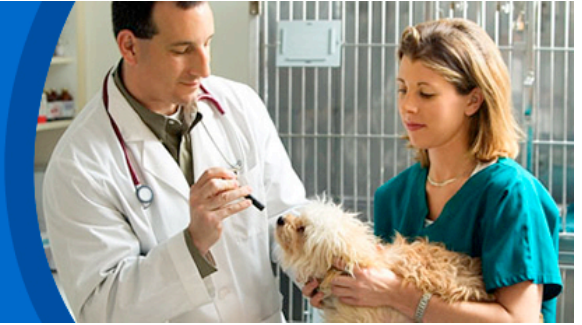




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Co-products of the biofuel industry as livestock feed: Opportunities and challenges

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ABSTRACT

The global drive to expand renewable energy has made biofuels, chiefly bioethanol and biodiesel, integral to the energy sector, with biomass conversion the most cost-effective route for producing renewable liquid fuel. Since these fuels are derived largely from grains, sugar crops and oilseeds, their processing generates large volumes of co-products of considerable value as livestock feed. Bioethanol manufacture yields corn gluten feed and meal, distillers dried grains with solubles, vinasse and bagasse, while biodiesel manufacture yields glycerol, fatty acid distillate and oilseed cakes, including from non-conventional plants such as *Jatropha* and *Camelina*. These co-products differ widely in protein, energy, fibre and antinutritional content, and hence in safe inclusion levels across ruminant, swine, poultry and fish diets. Judicious use lowers feed cost and supports sustainable livestock production, though contamination and batch variability require careful management. This review examines these co-products, their composition, and their potential and limitations as livestock feed.

Keywords: Biofuel co-products, Distillers dried grains, Corn gluten feed, Glycerol, *Jatropha* meal

Authors

1. Introduction

Conversion of biomass into liquid fuel is presently the most cost-effective pathway for producing renewable energy, and biofuels together account for the majority share of renewable energy produced globally [1]. Ethanol and biodiesel, the two principal biofuels produced worldwide, are derived predominantly from grain and sugar crops in the case of ethanol, and from oilseeds in the case of biodiesel. The desire to enhance energy security, curb greenhouse gas emissions and stimulate rural development has led many governments to frame policies mandating or incentivising biofuel blending, contributing to a marked rise in global biofuel output.

This expansion has a direct bearing on livestock production, since processing grains and oilseeds for fuel generates large quantities of fibrous, protein-rich and energy-rich residues. Rather than being treated as waste, these residues can be recycled into livestock diets, easing the competition between the food, feed and fuel uses of the same raw material. The co-products differ considerably depending on the feedstock and processing route, whether wet-milling or dry-grind for ethanol, or transesterification for biodiesel, so the feed value of each must be assessed individually. This review consolidates current knowledge on the major co-products generated by the bioethanol and biodiesel industries, their nutritional composition, and their potential and limitations as livestock feed ingredients.

2. Materials and Methods

This review is based on a structured search of peer-reviewed journal articles, institutional feed-composition databases and technical reports using the search terms "biofuel co-products", "distillers dried grains", "corn gluten feed and meal", "glycerol livestock feed" and "*Jatropha* and *Camelina* meal". Sources consulted included Feedipedia, the National Research Council nutrient requirement publications, the Bureau of Indian Standards, Food and Agriculture Organization technical reports, and peer-reviewed journals such as the Journal of Dairy Science, Journal of Animal Science and Food Chemistry. Publications reporting the nutrient composition, safe inclusion levels and feeding trials of biofuel co-products across ruminant, swine, poultry and fish diets were reviewed and synthesised under thematic heads relevant to the objectives of this review.

3. Co-products from bioethanol production

Ethanol is produced mainly through wet-milling or dry-grind processing of cereal grains, and the process of grinding, liquefaction, saccharification, fermentation and distillation yields a stillage fraction that is further processed into several distinct co-products, namely corn gluten feed, corn gluten meal, distillers grains, vinasse and bagasse (Erickson *et al.*, 2005) [2].

3.1 Corn gluten feed and corn gluten meal

Corn gluten feed and corn gluten meal are both obtained from the wet-milling of maize grain for starch or ethanol production, but they differ substantially in composition and use. Corn gluten feed is a fibrous, moderate-energy co-product, about 2000 kcal/kg, whose relatively high fibre content helps reduce the risk of rumen acidosis, making it a versatile, cost-effective ingredient for ruminants. Corn gluten meal, by contrast, is a protein-rich, low-fibre co-product with an energy value of about 4000 kcal/kg that serves as an important protein and energy source in poultry rations and is valued in pet food for its high protein digestibility; in some countries it is also used as an organic fertiliser and weed suppressant. Both co-products may carry elevated levels of aflatoxin B1 and therefore require quality monitoring (Feedipedia, 2018) [3].

3.2 Distillers dried grains with solubles

Distillers dried grains with solubles (DDGS) is produced by concentrating the thin stillage, or condensed distillers solubles, obtained after distillation and drying it together with the coarse distillers grains fraction. As a feed ingredient, DDGS is characterised by a relatively high protein and energy content, a high proportion of rumen bypass protein, about 55 percent of crude protein, and a low starch content that limits the risk of subacute rumen acidosis associated with high-energy rations. It also contains dried yeast cells that supply B-vitamins, improve palatability and support microbial protein synthesis, along with highly digestible neutral detergent fibre that stimulates rumen microbial activity. Its colour ranges from very light to very dark and its odour from normal to smoky, depending on the drying conditions employed (National Research Council, 2007) [4].

Table 1. Nutritional composition of corn gluten feed and corn gluten meal

Parameter (% DM)	Corn Gluten Feed	Corn Gluten Meal
Crude protein	18–22	60–65
Crude fibre	6–10	1–2
Ether extract	3–4	2–3
Lignin	1–2	0.2–0.4
Neutral detergent fibre	31–49	5–8
Acid detergent fibre	8–13	2–4
Ash	6–7	2–4

Source: (Feedipedia) [3]

Corn DDGS and rice DDGS differ appreciably in proximate composition. Corn DDGS typically contains around 38 percent crude protein, 2617 kcal/kg metabolisable energy, 10.7 percent crude fat, 0.29 percent calcium and 6.0 percent crude fibre, whereas rice DDGS contains a higher crude protein content of about 46 percent, 2883 kcal/kg metabolisable energy, 4.5 percent crude fat, 0.73 percent calcium and 4.9 percent crude fibre (Bureau of Indian Standards, 2024) [5]. Because of its favourable nutrient profile, DDGS can be included in the diets of a wide range of livestock species, although recommended maximum inclusion levels vary with species and physiological stage, ranging from about 10 to 20 percent in poultry diets to as high as 30 percent in growing heifers and pig diets (Kalscheur *et al.*, 2012) [6].

3.3 Vinasse and bagasse

Vinasse, the principal liquid by-product of ethyl alcohol distillation from cassava, sugarcane, sweet potato and sweet sorghum, is commonly used to prepare multi-nutrient blocks that improve nutrient utilisation and productivity of animals fed low-quality, roughage-based diets, and is also used as an organic fertiliser in some countries. Sugarcane bagasse, the fibrous residue remaining after juice extraction, consists mainly of cellulose, about 50 percent, hemicellulose, about 27.9 percent, and lignin, about 9.8 percent. Its high lignin content and low levels of soluble carbohydrates and nitrogen give it poor rumen degradability, and attempts to feed sugarcane or sorghum bagasse to livestock have generally proved economically unsuccessful; it is therefore more commonly diverted for use as fuel within the sugar and ethanol industry itself (Kewalramani *et al.*, 1988) [7].

4. Co-products from biodiesel production

Biodiesel is produced mainly from triacylglycerol-rich oilseeds such as soybean, canola, palm and rapeseed through a transesterification process, and this process yields several co-products of nutritional relevance to livestock, including glycerol, fatty acid distillate, and various oilseed cakes and meals such as palm kernel cake.

4.1 Glycerol

Glycerol, or glycerin, is a colourless, odourless, hygroscopic and sweet-tasting viscous liquid co-product of biodiesel production. In dairy cow diets it is commonly used as an energy source, particularly during the transition period after calving, and as a preventive measure against ketosis; an inclusion level of up to about 15 percent has been recommended, although its methanol content can pose a toxicity risk that is more pronounced in monogastric species (DeFrain *et al.*, 2004) [8]. In pigs, glycerine provides an energy value similar to that of maize and can be included at up to about nine percent for sows, six percent for weaners and 15 percent for finishers, while its use in fish diets remains less clear and warrants further study (Schieck *et al.*, 2010) [9]. Elevated concentrations of crude glycerin have also been evaluated in beef cattle feedlot diets with respect to performance, carcass traits and ruminal metabolism (Van Cleef *et al.*, 2019) [10].

4.2 Fatty acid distillate and oilseed cakes

Fatty acid distillate, a by-product of vegetable oil refining, is a good source of dietary energy. When reacted with calcium oxide it forms a rumen-protected fat that shields fatty acids from ruminal biohydrogenation; feeding this protected fat augments the oleic, linoleic and stearic acid content of dairy milk fat while reducing its palmitic acid content. Palm kernel cake, another widely available oilseed by-product, has also been evaluated as a partial replacement for cottonseed cake in growing buffalo calves, though its use is limited by antinutritional factors such as phytic acid.

5. Co-products from toxic oilseed plants

Certain oilseed crops used for biodiesel production, most notably species of *Jatropha*, contain inherent toxic and antinutritional compounds that constrain the direct use of their co-products as livestock feed.

5.1 *Jatropha* kernel meal

The kernel of *Jatropha curcas* L. seeds, obtained after removal of the shell, contains about 50 to 60 percent oil that can be used either as an edible oil or converted into high-quality biodiesel. The defatted kernel meal remaining after oil extraction is an excellent source of nutrients, containing about 60 to 65 percent crude protein, with essential amino acid levels, except lysine, exceeding those of soybean meal in the case of the non-toxic species *Jatropha platyphylla* Müll. Arg. (Makkar *et al.*, 2011) [11]. However, the presence of antinutritional factors such as phorbol esters, lectins and trypsin inhibitors in most *J. curcas* genotypes limits the direct use of the kernel meal as a livestock feed ingredient and generally necessitates detoxification (Makkar *et al.*, 2009; Rakshit *et al.*, 2008) [12, 13]. Notably, *J. platy*

phylla is free of phorbol esters, the principal toxin present in most other *Jatropha* species, making it a more promising candidate for direct incorporation into feed (Makkar *et al.*, 2011) [11].

5.2 *Camelina sativa* meal

Camelina sativa (L.) Crantz, commonly known as false flax and belonging to the Brassica (Cruciferae) family, yields a meal containing about 36 to 40 percent crude protein that is rich in essential amino acids, including lysine and methionine. *Camelina* meal can be included at about 10 percent in poultry, layer and broiler, diets. Compared with birds fed a conventional maize-soybean diet, hens fed *Camelina* meal show an eight- to ten-fold increase in total omega-3 fatty acids and alpha-linolenic acid in eggs, along with a favourable decrease in the omega-6 to omega-3 fatty acid ratio, a recognised indicator of nutritional quality; two large eggs from *Camelina*-fed hens can supply over 300 mg of omega-3 fatty acids to the human diet (Bean-Hodgins *et al.*, 2003; Cherian *et al.*, 2009) [14, 15].

6. Results and discussion: benefits, knowledge gaps and future research needs

Biofuel co-products frequently substitute for higher-priced conventional feed ingredients. Because DDGS and maize prices are closely linked and their correlation has strengthened in recent years, the availability of DDGS and other co-products buffers livestock producers against fluctuations in cereal grain cost. Being good sources of protein and energy, these co-products can partially replace soyabean meal and maize in ruminant, pig and poultry diets, lowering feed costs while reducing the environmental footprint of both the biofuel and livestock sectors and fostering greater resource-use efficiency.

Nonetheless, several knowledge gaps remain. Batch-to-batch variability in nutrient composition, arising from differences in feedstock and processing conditions, complicates precise ration formulation, and the risk of mycotoxin contamination, particularly aflatoxin B1 in corn gluten feed and meal, requires continuous monitoring. Detoxification protocols for toxic oilseed meals such as *Jatropha curcas* kernel meal need further refinement and validation across species, and the safe use of glycerol in aquaculture diets remains poorly defined. Long-term studies on animal health, reproductive performance, product quality and life-cycle environmental impact would further strengthen the case for wider adoption of these co-products.

7. Conclusion

The rapid expansion of the global biofuel industry has generated a diverse array of co-products, ranging from fibrous residues such as bagasse and vinasse to protein- and energy-dense products such as corn gluten meal, distillers dried grains with solubles, glycerol and specialty oilseed meals. When their nutrient composition, antinutritional factors and safe inclusion levels are properly understood, these co-products can serve as valuable and cost-effective alternatives to conventional feed ingredients such as maize and soyabean meal across ruminant, swine, poultry and, to a more limited extent, fish diets. Their strategic use not only reduces feed costs for the livestock sector but also improves the overall resource efficiency and environmental sustainability of the biofuel value chain. Continued research into detoxification techniques, quality standardisation and species-specific inclusion guidelines will be essential to fully realise the potential of biofuel co-products as livestock feed.

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