

## Novel coproducts from corn milling and their use in ruminants' nutrition

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**Abstract:** The article reviews published data on two novel coproducts originating from corn milling: high-protein distillers' grain (HPDG) and reduced-fat distillers' grain (RFDG). Based on a literature survey over the last decade, this article focuses on their chemical composition and, consequently, nutritive value and on the effects of their inclusion in ruminants' diets on rumen activity and animal performance. Compared to the classic distillers' grains, the two new coproducts expressed lower variability of their chemical composition, nutritive value, and specific feeding characteristics, allowing more targeted feeding strategies (protein balancing, avoidance of milk fat depression, etc.). Thus, HPDG has significantly higher crude protein content (~44%), lower fat content (~4.3%), and lower fibre content (~26.8% neutral detergent fibre (NDF) and ~12.3% acid detergent fibre (ADF)) compared to the classical distillers grains. In the case of RFDG, only the fat content is significantly lower (~4.8%), whereas the crude protein content (~32.1%) and the fibre content (~36.1% NDF and ~14.7% ADF) are only slightly lower compared to the classical distillers grains. On this basis, HPDG can successfully replace classic high-protein meals, such as soybean meal, thus providing high levels of rumen undegradable protein, although it has the same amino acid limitations as the originating raw material, corn grains. The use of RFDG instead of the classical distillers' grains allows much higher dietary inclusion, without adverse effects on rumen metabolism and animal performances. A further development of the two coproducts and further diversification of corn coproducts, allowing better solutions to various feeding situations, is expected.

**Key words:** Corn milling, high-protein distillers' grains, reduced-fat distillers' grains, rumen, feeding efficiency

### 1. Introduction

The valorisation of corn coproducts as feedstuffs relies not only on the large available quantities but also on their special feeding characteristics (1–3). Corn processing supplies the feed market with a broad range of coproducts from the production of alcohol, starch, oil, sweeteners, etc. (4), which favours better adaptability of the feeding strategies to various practical situations (5). Moreover, the new processing techniques (6,7) aim to extract as much as possible from the raw materials, especially fractions with high economic value such as starch, fructose, oil, coatings, textiles, adhesives, etc. (8,9), and to fractionate the raw materials into high-, mid-, and low-value components that can be used for targeted markets and specific uses (6,10). This continuously generates novel or updated coproducts available for farm animal feeding; however, these coproducts are often marketed under misleading or incorrect names or they have variable quality and nutritive values (11,12), which impairs their efficient use in animal nutrition.

Coproducts from corn milling have been extensively studied in the last decades from various angles: the nutritive value and its variability, the processing conditions, the inclusion in various feeding strategies, and the effects on animal performance, digestibility of fibre fractions, quality of proteins (dynamics of rumen degradability, amino acids), etc., such that most of them are well described in the literature (4,11,13). On the other hand, certain changes in the processing techniques led to coproducts that significantly differ from the classical ones in terms of nutritive value, effects on rumen metabolism and animal performances, their use in feeding strategies, etc. (12,14).

Of these emerging coproducts, two were selected for this review based on their novelty, the critical mass of scientific knowledge, and the issues raised by their valorisation in ruminant feeding: high-protein distillers' grains (HPDG) and reduced-fat distillers' grains (RFDG). Although reported in the recent literature, these feeds are not yet included in publicly available feeding tables such as Feedipedia, Norfor, etc., and they clearly differ from

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classical distillers' grain (DG), with or without solubles. The differences are not only in nutrient composition and nutritive values, but also in the appearance, i.e. colour and texture (9,10). The scientific literature of the past decade was screened for articles referring to the use of the coproducts HPDG and RFDG in ruminant feeding focusing on their chemical composition, nutritive value, and effects on rumen functions and animal performance. Only coproducts from corn milling were included in the review.

## 2. Processing techniques

HPDG is a relatively new coproduct obtained from various processing techniques aiming to eliminate nonprotein fractions from the final coproducts. An example is the implementation of the BFRAC ("Brion fractionation") technology (15), which consists of removal of hulls/bran and germs prior to fermentation and the adding of the soluble fraction to the bran, not to the DG. Therefore, DG is dried separately, leading to a coproduct that is rich in protein and has low contents of fibre, fat, and phosphorus. BFRAC technology can be accompanied by BPX technology (raw starch hydrolysis), which eliminates the traditional cooking stage and replaces it with the use of enzymes to predigest the starch prior to fermentation (16). BFRAC technology allows better valorisation of various fractions while BPX technology allows energy/fuel savings and reduction of costs.

RFDG is a coproduct generated rather as a result of market reasons than by development of new processing techniques. As the cost of extracting corn oil is lower than its price, this drives processors to update their technological flows accordingly. Thus, in recent years, there has been a strong tendency to shift from regular DG to RFDG, using various techniques/approaches (solvents, degermination, separate valorisation of soluble fraction, etc.). Beside the regular cautions related to coproducts such as transparency of the processing technology, consistency of batches, and the need for periodical chemical analyses (17), two more issues need to be highlighted.

On one hand, the partial removal of fat lowers the energy value of DG and therefore its commercial value. Thus, there are some concerns that the reduction of fat has, in some situations, more disadvantages than advantages. The loss of energy has to be balanced by inclusion of energy-rich ingredients, leading to supplementary costs compared to the regular DG. Some farmers may not be aware of the trend of reducing the fat content of DG, leading, in the absence of periodic chemical analyses, to errors in diet formulation, e.g., feeding situations where energy is the limiting factor.

On the other hand, a lower level of fat generally prevents the problems that occur when the fat content of the diet is too high (impairment of rumen fermentations, milk

fat depression, oxidation, etc.). A lower fat content would allow a much higher inclusion of DG in diets (presumably more economic than the classical feeds), without the fear of adverse effects for animals. The flowing properties are also improved after fat removal (18), making RFDG more suitable for inclusion in the compound feeds. Removal of fat contributes to a clearer clustering of the coproducts and better feeding strategies, e.g., RFDG is a protein feedstuff, while DG is an energy-protein feedstuff. Beyond the debate on the fat content, RFDG is a novel feedstuff on which scientific reports are already available and its usage is likely to increase in the future.

## 3. Chemical composition

Both HPDG and RFDG showed lower variability of chemical composition and, consequently, of the feeding values as compared to classical milling coproducts. It is well known that such variability is a major obstacle in the appropriate use of coproducts in animal feeding (4,12). As these two coproducts have been developed in recent years (when analytical methods were well developed) and within a widely spread industry having a large potential to produce them, the data on their chemical composition (proximate analyses, minerals, amino acids, etc.) are relatively abundant. (Table). Although the two new coproducts are expected to have low variability in their chemical composition (19), there are still some variations, e.g., in neutral detergent fibre (NDF) or acid detergent fibre (ADF). Beside the possible influences of the applied analytical methods, this variability may be determined by the variation in raw materials traits, content of residual fat, and processing conditions (17,20,21). This maintains the need for their periodical analysis, similarly to regular DG, especially when changing the provider (11).

Compared to classical DG (4), the chemical composition of RFDG differed mostly by the much lower crude fat content (4.8% vs. 11.2% , DM basis), whereas the average protein content was slightly higher, probably due to a concentration effect induced by the extraction of fat. However, this effect was not expressed in the case of fibre content, where variability caused by the raw materials or by the processing conditions seemed to be more important. The crude fat content of RFDG was quite variable, as also observed by other authors (21). Although various analytical methods were used, this may show that the efficiency of fat extraction and the decision on how much fat to extract could be determinants for the fat content of various batches. The fat and protein content of HPDG are respectively much lower and much higher than those of classical DG. They are also much less variable than the fat and protein content of RFDG and therefore more predictable. On the other hand, both HPDG and RFDG allow more targeted feeding strategies, e.g., for protein balancing (22).

**Table.** Chemical composition of reduced-fat and high-protein distillers' grains (g/kg DM).

	OM	CP	EE	NDF	ADF
High protein distillers' grains					
Tedeschi et al., 2009 (5)	981	446	42	273	204
Kelzer et al., 2010 (12)	958	454	40	225	60
Robinson et al., 2008 (19)	981	411	53	231	111
Jacela et al., 2010 (25)	982	408	54	366	22.9
Widmer et al., 2007 (26)	965	445	40	177	94
Widmer et al., 2008 (27)	-	486	34	-	-
Maxin, 2013 (28)	930	403	40	262	135
Christen et al., 2010 (30)	981	445	34	287	219
Hubbard et al., 2009 (48)	-	461	46	264	156
Abdelquader, 2009 (42)	-	452	33	258	69
Kelzer et al., 2009 (51)	975	461	46	264	156
Swanepoel et al., 2014 (61)	978	395	55	338	-
Average	970	439	43	268	123
Standard deviation	16.2	26.9	7.5	49.1	60
Reduced fat distillers' grains					
Saunders and Rosentrater, 2009 (9)	-	340	27	-	-
Atkinson et al., 2012 (21)	-	294	77	305	133
Mjoun et al., 2010 (23)	947	340	35	428	125
Mjoun et al., 2010 (24)	958	345	35	450	129
Gigax et al., 2011 (56)	-	348	67	-	-
Schroer et al., 2014 (57)	-	341	47	372	199
Castillo Lopez et al., 2014 (58)	918	318	27	250	-
Faulkner et al., 2012 (60)	-	242	70	-	-
Average	941	321	48	361	147
Standard deviation	20.7	36.7	20.4	83.6	35.2
HPDG / RFDG	103%	137%	90%	74%	84%
Classical DG*	-	308	112	390	161

\*Reference value, from the review of Schingoethe et al., 2009 (4).

As for the mineral and vitamin components, it is expectable that RFDG have a similar profile to that of classical DG, as the only difference is the removal of oil to a variable extent. In the case of HPDG, the situation is more complicated, as the new product is not similar to any of the classical coproducts of dry milling. For example, because a large proportion of corn phosphorous is found in germs,

a low level of this mineral is expected in HPDG following the removal of germs. Profiles of minerals and/or amino acids were sporadically reported both for RFDG (23,24) and HPDG (19,25–29).

As they originate from corn, the new by-products presumably have the shortcoming of low lysine content, as already reported for HPDG (4,27,30). These authors

also showed that the content of phosphorous (as well as of other minerals) is lower in HPDG than in classical DG. This is consistent with the findings of Cao et al. (31), who showed that, of the fractions resulting from corn milling, the phosphorous is found in the soluble fraction, a milling by-product that is never included in HPDG.

Since the low fat content of RFDG opens the possibility of maximising the inclusion of this coproduct in diets, its sulphur content becomes particularly important (32). The few published data on mineral composition of RFDG (23,24) revealed that its sulphur content (0.74%–0.82%) is higher than the range observed for the classical DG: 0.33%–0.74% (20). It was shown that high dietary sulphur content, including that originating from DG (33), influences rumen metabolism, being associated with lower rumen volatile fatty acid (VFA) and higher rumen ammonia (34); decreases dry matter intake and dietary energy efficiency (35); and causes health problems, such as polioencephalomalacia (36). These have already triggered specific research that showed that risks are higher in the case of wet rather than dry DG (37) or investigated potential solutions such as treating DG with sodium hydroxide (38). However, further studies are needed in order to better understand all the factors involved in the rumen metabolism of sulphur and to develop efficient strategies to mitigate its negative effects (39).

Other chemical composition data, such as the profiles of fatty acids, are reported, albeit less frequently, in the literature. There are reports (27) that mention that fatty acid profiles of HPDG and classical DG are similar and both are close to the profile of fatty acids in the whole corn grains, but more data are needed in order to allow clear assessments.

#### 4. Feeding value and effects on rumen metabolism

While data on chemical composition are frequently reported, information on the biological parameters determining the feeding value and the effects of these new distillers' coproducts on the rumen environment are still scarce.

Emergence of RFDG revitalised the old debate on the effects of excessive fat content on rumen fermentation (40). In time, various trials focused on the effect of the levels and forms of corn fat on the rumen environment and, subsequently, on animal performance (3,4,11). A practical recommendation is that regular DG should contain high levels of fat in order to economically benefit from its higher energy value, but caution is needed not to exceed the threshold of the overall dietary fat proportion, leading to impairment of rumen metabolism.

Besides the dietary level of the fat, its form is also important. For example, a comparison of three sources of corn fat (condensed distillers' solubles, distillers' grains plus solubles, and oil as such) revealed that, at a dietary fat level

of 8.8%, out of which 5% was supplied by corn coproducts, the inclusion of oil as such was detrimental for rumen functions, whereas 40% participation of DG (supplying the same amount of fat) improved animal performance compared to the corn-based control diet (41). One explanation offered by the authors was that whereas the corn oil freely interacts with rumen microbes, the fat from DG was less exposed to the rumen environment, being trapped in ground corn germ particles and released more slowly; therefore, its detrimental effects were less marked. These findings were confirmed by other authors (42), who also observed differences between corn coproducts, corn germ being more effective than distillers' dried grains with solubles in protecting the oil against rumen digestion.

Although the fat content of both HPDG and RFDG is low, such particularities are to be taken into account when assessing their specific effects at rumen level. Another issue to be taken into account is the variable effect of the same level of fat based upon diet composition and type of fibre. Overall, the removal of fat allows much higher dietary inclusions of RFDG, without fearing the detrimental effects of excessive fat.

The digestion of proteins and amino acids contained in the new products can be still considered a knowledge gap. Rumen degradability of corn coproducts and the amino acids profiles and behaviour in the rumen is expected to be similar to that of the original corn, but various processing techniques (e.g., fermentation, separation) and conditions might induce significant changes (11,43) and therefore each coproduct has its own characteristics that have to be assessed. As the two new products are not fundamentally different from classical DG (at least RFDG), their rumen degradability should remain in the same range. There are limited literature data on the rumen degradability of the new coproducts. Similar proportions of rumen undegradable protein (RUP) were observed (44) for RFDG (60.4%) and HPDG (54.5%), both similar to the RUP of classical DG (52.3%). However, other studies (29) revealed bigger differences between nitrogen degradability of HPDG, of 48.2%, compared to classical distillers' dried grains with solubles, of 84.8% (values uncorrected for particle loss). Higher rumen degradation for low-fat distillers' grains, e.g., of 76.9%, was also reported (45). It has to be mentioned, however, that the general variation of RUP observed in case of classical corn coproducts is rather large, e.g., from 53.6% to 71.7% (46), and the new coproducts may express the same behaviour. The new coproducts may also influence the microbial protein synthesis: there are reports (47) that lipid extraction increases the availability of rumen degradable protein (RDP), while the high RUP content of HPDG may contribute, in certain situations, to the decrease of the ruminally available nitrogen, a determinant factor of protein synthesis.

All these points strengthen the need for continuous research in order to keep up with the changes in ethanol production processes (48).

Although the new by-products have lower fibre content than classical DG, the positive effects of the latter on the evolution of rumen pH, when it is included in ruminants' diets at the expense of cereals or other sources of nonstructural carbohydrates (49), is likely to occur in the case of HPDG and RFDG, too. Like classical DG, the new by-products have a quite high content of digestible fibres, which means they have the potential of ensuring high levels of dietary energy while being less acidogenic than feeds that are rich in starch and other nonstructural carbohydrates (50). However, it has to be noted that such changes in rumen metabolism occur only at high dietary levels. For example, 15% inclusion of HPDG did not induce major differences in rumen fermentation or digestibility (51).

While the dietary proportion of RFDG can increase up to 70%, the influences of its sulphur content on rumen metabolism becomes accordingly important. The sulphur may decrease VFA concentration (35) and affect site and extent of fibre and protein digestion (52).

An important concern for corn coproducts in general is their quality; this also applies to HPDG and RFDG, as only some parts of the processing technology are changed. Although the technological processes are more and more controlled, processors pay more attention to the production efficiency and quality of the main products and sometimes neglect the quality of the coproducts. Thus, poor control of the drying conditions may lead to a decreased digestibility of protein and fibre (19,43), high occurrence of mycotoxins (17,53,54), or high differences in quality among batches and producers (17). More research is needed on this subject in order to assess the incidence of these quality problems and to develop specific tools for prevention or mitigation.

### 5. Effects on ruminant yields

Numerous experiments on various coproducts from processing corn and other cereals for various purposes have been performed over time in order to assess the effects on ruminants' yields (4,11). However, the constant development of the processing technologies and strategies has led to a constant need for assessment of new or updated coproducts in terms of feeding value and effects on rumen metabolism and also in terms of effects on the production performance of various categories of farm animals. The emergence of two new coproducts on the feedstuffs market triggered a series of specific studies. Such studies may refer to the influence of the raw material, e.g., sorghum or wheat instead of corn (2,55), but only studies on corn were considered for the present review.

A distinct group of studies refers to the comparison between classical DG and RFDG. Thus, the comparison (56) of wet DG with low (69 g/kg DM) and regular (129 g/kg DM) fat content in steers' diets (35% inclusion in diet) led to the conclusion that better growth performance was obtained with the regular-fat DG, whereas the low-fat form induced performances similar to the control (high-moisture corn and dry-rolled corn mixture). In dairy cows, the direct comparison (23) of the DG and RFDG revealed no significant differences in dry matter intake (DMI) and milk yield and composition, except for a tendency ( $P = 0.14$ ) of the latter to increase milk fat content from 32.4 to 35.7 g/kg. It should be mentioned, however, that the dietary participation of the corn by-products was moderate and the diets were designed to be equal, not just in overall feeding value but also in nutrient supply such as fat (5.6%–5.7% of DMI for all treatments), RUP:RDP ratio, NDF, ADF, minerals, etc. The same lack of differences was observed for the DMI and growth of heifers (57) fed diets containing either regular or reduced-fat DG, at a dietary level of 20%. Other studies report the influence of corn oil (as such or through DG) on animal performance. It was found (58) that including 1.5% of corn oil or 15% DG (having 108 g/kg DM fat content) had no detrimental influence on milk yield and composition. It was also shown (41) that DG can be included in the steers' finishing diets up to a corn fat equivalent inclusion of 5% without any detrimental effects on rumen processes. These points confirm the fact that regular DG is a better option, as long as the overall dietary fat supply is not excessive and impairing the rumen functions. For practical situations when high dietary levels of DG are a tool to reduce the feeding costs, the partial removal of fat is necessary.

When assessing the effects on animals' performance, RFDG is usually compared with mixtures of feeds: soybean meal + hulls, soybean meal + corn, alfalfa hay + soybean meal + corn, high-moisture corn + dry-rolled corn, soybean meal + corn silage, etc. Inclusion of gradual increasing levels (0%, 10%, 20%, and 30%, on DM basis) of reduced-fat distillers' grain with solubles (RFDGS) in dairy cow diets in order to replace soybean meal and soybean hulls had no influence on DMI and milk production (24). On the other hand, milk fat content increased linearly (from 31.8 to 37.2 g/kg) and milk protein exhibited a quadratic response (with maximum level at 20% inclusion of RFDGS). Milk urea nitrogen as well as feeding efficiency (milk yield:DMI) increased linearly. In a related article (23), replacement of soybean meal and soybean hulls by either classical DG with solubles or RFDGS at a moderate dietary level of 20% did not induce differences in DMI, milk yield, milk fat, or lactose content among treatments, while milk protein was higher with both DG and RFDG diets compared to the control

group, leading to improvements of the feeding efficiencies. Other authors (59) also showed that for gradual increase of dietary RFDG, up to 30%, on the expense of corn silage, corn grain, and alfalfa hay, the lactation performances were maintained, with a tendency to increase the protein content of milk. High levels of RFDG in diets for beef cows of fattening steers are a good tool to lower the feeding costs (21,60), as the animals' productive performances are not impaired. In some cases, the low fat concentration allowed dietary inclusions of up to 70% without major adverse effects on animal performances (21,32), but the authors underlined that more research is needed before setting a general recommendation.

The studies on HPDG usually focused on comparison with soybean meal, a classical reference when assessing the feeding value of DG and their effects on animal performance. In a multiple comparison (30) among HPDG, DG, soybean meal, and canola meal, similar DMI, milk production, protein and fat yields, and feed efficiency among treatments were reported. On the other hand, milk fat content of the HPDG-fed group was similar to that of the soybean meal group and both were higher than the milk fat content of the DG and canola meal groups. The level of inclusion in DMI was 12% for HPDG, 11% for soybean meal, 12.7 % for canola meal, and 22% for DG, ensuring an equal supply of protein. HPDG was associated with the highest concentration of casein in milk, suggesting that it might have the most desirable amino acids profile for casein production. The authors highlighted, however, that lysine is the first limiting amino acid, as also shown by other studies (28,61), which warns about the potential lysine deficiency of HPDG, especially at high dietary proportions. Moreover, lysine is highly susceptible to heat damage (17), which makes important the influence of processing conditions and highlights the need of specific analysis when large quantities of corn coproducts are involved. When replacing a mixture of soybean meal and Soy Pass in diets of dairy cows at 20% of DMI (48), HPDG induced an increase of the milk yield and fat-corrected milk (from 31.6 to 33.4 L/day and from 33.2 to 36.3 L/day, respectively) that also induced further increase of the feeding efficiency. The DMI and the content of milk fat and protein were not significantly influenced.

Although the fat content of the new coproducts is rather low, it has to be mentioned that corn fat has specific effects on milk fatty acids, e.g., increasing the concentration of trans-11 C18:1 and cis-9 trans-11 CLA (42). This effect was achieved at an inclusion level of 30% DG with 9.9% fat content and therefore may also occur when high

dietary levels of RFDG (>60%) are used. Other effects on the quality of animal products were also sporadically reported. At a dietary level of 35%, no differences between normal DG and RFDG were found for carcass quality traits such as the longissimus muscle area, 12th rib fat thickness, and marbling (56). There are reports that even at higher dietary levels of 70%, RFDG did not negatively influence the carcass characteristics, meat quality, or lipogenic activity (21). However, at this high dietary level, other authors (32) observed inconsistent effects on carcass characteristics. These contradictory results and, in general, data scarceness leave open the research on the effects of the new coproducts on animal product quality.

## 6. Conclusions

The recent literature revealed that HPDG and RFDG can be considered as distinct feeds: the protein content of HPDG is systematically higher (+37%), while the proportions of fat and fibres are systematically lower (-15% and -32%, respectively) than in RFDG. This is supported also by the differences in processing technologies (prior removal of bran and germs in the case of HPDG and partial removal of oil in the case of RFDG).

The available information on RFDG and HPDG show their potential to be used as protein feedstuffs. The main traits valuable for diet formulation are the high protein content, low rumen degradability, and content of intestinally digestible amino acids. Both coproducts are successful in replacing conventional feeds such as soybean meal or other protein feeds without compromising rumen metabolism and animal performance. Moreover, due to their particular feeding characteristics, they are valuable options for complementing the basal diets (e.g., cheaper sources of RUP). A potential problem may be their contamination with harmful substances, e.g., mycotoxins, if the quality control of the cereals is not well regulated. The review also revealed several knowledge gaps related to the new coproducts: the fate of individual amino acids in the rumen, their effects on the dynamics of rumen pH, the sulphur activity at rumen level, maximal level of RFDG in diets, mycotoxins' load, etc.

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