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Effect of Treated Corn Distillers Dried Grains with Solubles as Dietary Supplement on the Growth and Healthy Performance of Pigs: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Author WTG designed the study, collected data, wrote the first draft of the manuscript, and managed the literature. Author EAS helped in literature search. Author JHL supervised the whole work. All authors have read and approved the final and revised version of the manuscript.

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Review Article

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ABSTRACT

The objective of this paper is to review the effects of treated corn Distillers Dried Grains with Soluble (DDGS) fed to pigs, specific on growth performance, nutrient digestibility, and health status. As industrial ethanol production increases, there is a simultaneous increase in co- products, Distillers Dried Grains with Solubles. Utilization of DDGS as a dietary supplement in monogastric reduces feed costs. In terms of the nutritional value, DDGS is rich in fiber and protein, however, DDGS is indigestible in pigs if not treated. Therefore, a lot of research have been conducted about its treatment and nutritional effect on growth performance, nutrients digestibility of growing pigs, weaned pigs, sows, and finishers. Treated corn DDGS increases feed intake, gain weight, and it also improves nutrient digestibility and reduces the severity of lesions in the ileum and colon of pigs, considering the DDGS with absence of undesired levels of mycotoxins. A number of different types of treatment that exists, however, hydrolysis with the usage of microorganisms and their

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enzymes has shown positive impacts on DDGS polysaccharides (fiber). Other types of treatments are also reviewed but more attention has been given on microbial and enzymatic hydrolysis by the reason of being familiar in the gastrointestinal tract (GIT) as a complex organ system where break down of complex polysaccharides into simple ones for pig efficiency utilization and absorption takes place. Furthermore, the characteristics, composition, and nutritional value of DDGS, in pig production are discussed into this paper. In conclusion, treated corn DDGS increases feed intake, gain weight, improves nutrient digestibility and the health status of pigs.

Keywords: Corn distillers dried grains with solubles; feed; pigs; treatment.

1. INTRODUCTION

Increased ethanol production leads to higher quantities of co-products that can be utilized in livestock feeding [1-4]. Dried distillers' grain with soluble (DDGS) is one of the co-products that is produced during the distillation of grain [5]. DDGS has variable nutrient compositions which is largely dependent on the plant source [1,3,6]. Mostly, sorghum, corn, wheat, and barley are the grains that are used in ethanol processing, this contributes greatly on the resultant co-products nutritional variability [3,7,8, 9,10].

Crude protein, oil, and fiber (polysaccharides) are the main components of corn DDGS [2], and corn DDGS is included in monogastric diet at 10 to 20% [5], 20 to 30% according to the digestible protein (amino acids) and to the required percentages of the DDGS level necessary to the animal phase and category [11,12].

Energy and amino acids are the most expensive components in pig diets, their concentration plays a major role in determining the cost of complete ration [13]. Starch and amino acids are substrates that yield energy in pig diets [14], and the presence of nitrogen in protein, minerals and vitamins are essential for microbial health population in the hindgut [15].

The untreated corn DDGS has low digestibility in pigs and leads to increased fecal output which has negative environmental impacts, as result of mineral leaching and water pollution [16]. Therefore, it is necessary to develop strategies that mitigate such impacts, whilst improving its digestibility in pigs [16]. However, a number of research has been conducted on treated corn DDGS as a source of fiber and energy in pig diet, and its possible effects [17]. This paper reviews the effect of treated corn DDGS as feed supplement on the performance of pigs, and it begins on illustrating the nutritional value of DDGS, the reasons behind that contribute for its composition and the forms of treatment.

2. METHODOLOGY

Secondary data sources and publications from different international scientific research journals; Asian Journal of Research in Animal and Veterinary Sciences, Animal Feed Science and Technology, Agricultural Animal Feed Science, Animal Science, Animal Nutrition etc. were collected to compile the information in this review paper. Many papers from reputable journals that were searched through books, epic search engine, google scholar, Pub Med were read to obtain information on distillers dried grains with solubles production process, characteristics, usage, and its effects on pigs. Analysis of corn DDGS and its effects in pigs were based on literature obtained from reputable related journals.

3. NUTRITIONAL VALUE OF DISTILLERS DRIED GRAINS WITH SOLUBLE (DDGS)

DDGS is recognized as a valuable source of energy, protein, water-soluble vitamins, and minerals for animals [18,3]. Besides, it is readily available and cost-effective for sustainable animal production, however, it has low nutrient digestibility [6]. Despite this, DDGS is rich in nutrients and is of low cost making it an important ingredient to be included in pig diets [3,19]. For better utilization of DDGS as a dietary feed ingredient, it has to go through one or combined methods of treatment (chapter 3.5.1; 3.5.2; 3.5.3) to improve its digestibility and nutritional value [3].

Knowing the physical and chemical composition of DDGS is one of the key factors relevant to dietary formulation [20] or even before hydrolysis to improve fiber [3] or protein by enzymes, though it was studied as unbeneficial effect when it happens directly in animal body (Microbial fermentation in dietary Protein) [21]. Verifying the digestible and undigestible nutrient is an important parameter to evaluate feed value. The sources of DDGS such as the type of grain, the whole chain value process (industry process and management) contributes to the DDGS' quality [18].

3.1 Physical Characteristics of DDGS

Physical properties of DDGS involves particle size, moisture content, water activity, bulk density, angle of repose, energy content, thermal activities, odor, and color (Table 1). All these DDGS properties within ethanol plants, and that variation is caused by several factors [22] including: raw material (corn) characteristics, hammermill settings, conditions, additives, and chemicals used during processing, proportion of condensed distillers soluble added to wet distillers grains before drying, type of dryer used, drying time and temperature, cooling and conditioning of DDGS after drying, flat storage vs. vertical silo, final moisture content, cooling time prior to shipping, loading into transport vehicles and containers when hot, ambient temperature and humidity [23]. Color as a physical characteristic, is an attribute which is most affected by raw material quality and the heat used to process DDGS during the ethanol production [18,24,25], and it can be categorized in three qualities, from very light, golden yellow to very dark brown in color which is attributed certain points of numbers to grade them (Table 1 shows the average mean of their range) [23]. By the using of either Hunter Lab or Minoltas calorimeters, the color is measured to observe the DDGS' quality to the extent of heat damage, which may appear in a brown color [26].

Generally, odor is affected by conservation management and also by the heat process. Sweet smell is noted on golden DDGS as high quality, yet dark colored DDGS sources as a result of overheat presents burned smell [23]. Particle size is another important property for DDGS treatment, especially the hydrolysis treatment is influenced by this parameter. In combination with other physical property types, it is also a key character which is relevant for transportation and storage, and it goes on to implicate in pig digestion process [23]. The particle size may also have an influence in transportation, storage, and in digestive activities. On the 34 DDGS sources which had been analyzed in 2004 and 2005, the average particle size was about 665 and 737μm, Bulk density in lbs/ ft^3 31.2 and 25.2, and its pH average was 4.14 and 4.13, respectively [23]. Furthermore, according to the same author, bulk density is a physical property that affects the DDGS storage volume and transport costs, the lower bulk density is, the higher the costs. DDGS moisture content plays a great role as it determines its storability prior to use. DDGS has low moisture content (10–12%), which facilitates to prevent heating and spoilage [23]. In addition, studies of the estimation percentages of physical types of DDGS have been conducted and given. The following table (Table 1) shows the average mean of physical properties of more than 100 samples of DDGS from 6 dry ethanol plants.

3.2 Chemical Composition of DDGS

Crude protein (CP), crude fiber (CF), crude fat, neutral detergent fiber (NDF), acid detergent fiber (ADF), starch and ash are chemical properties of DDGS. The implication of chemical composition of DDGS is in the diet inclusion, especially when DDGS is over burnt during the production of ethanol, the crude protein will be lower than into unburnt DDGS [12,23]. High insoluble crude fiber is low in digestibility, less absorption in pig and nutrients excretion will result in high quantities. This crude fiber will require much labor on DDGS treatment, and this will end up by adding much cost in pig production. In summary, the chemical composition of DDGS affects the inclusion of DDGS in pig diet, and it implicates high cost in correcting the dietary formulation to enhance the nutritive quality. Studies conducted revealed that, many factors affect the chemical composition of DDGS [23]. The DDGS chemical composition ranges from 23.4 to 28.7% crude protein, 2.9 to 12.8% fat, 8.8 to 36.9% of acid detergent insoluble nitrogen (ADIN), 28.8 to 40.3% NDF, 10.3 to 18.1% ADF, and 3.4 to 7.3% ash, lysine concentrations range from .43 to .89% [18] and approximately 89% of dry matter, crude protein 27% and crude fiber 8.9% found on its chemical composition [29]. The average content of DDGS protein is 38% [9]. The crude protein concentration of good quality DDGS should be at least 27%, total fat 9%, total phosphorus 0.55%, ADF and NDF should not exceed 12 and 40%, respectively (Table 2) [12]. Additionally, to avoid sources of DDGS that have been heat damaged, the lysine to crude protein ratio should be at least 2.80% (Table 2) [12].

3.3 Application of DDGS in livestock feeding

DDGS is an important feed source supplement to livestock diet around the world [30] and it replaces corn and soybean meal in pig diets (Fig. 1 and Table 3), based on its nutritional and economic value [31-34,12,35]. Diets should be formulated based on standardized ileal digestible amino acids and digestible phosphorus, because its protein is low in lysine [36,12,35]. The findings of the research showed that, low lysine in DDGS protein it is as a result of overheating in the dry process during ethanol production (23,12]. Another reason, it might be associated with grain quality used and management from the source that is obtained the DDGS. To exclude heat damaged products from swine feeding, it is recommended that producers calculate the lysine to crude protein ratio and only use DDGS if this ratio is greater than 2.80% (Table 2) [12]. Additionally, crystalline L-lysine needs to be included in the diet containing DDGS [12]. Therefore, the inclusion of crystalline L-lysine should be increased by 0.10% for each 10% DDGS that is included in the diet formulated for nursery, growing, finishing pigs, and lactating sows, and 4.25% more than 20% DDGS is included in the diet, 0.015% of crystalline L-tryptophan also needs to be added to the diet for each additional 10% DDGS that is being used [12].

“If diets are carefully formulated, producers will be able to use 20% of DDGS in nursery and growing finishing diets without experiencing any pig performance reduction, and 30% of DDGS may be used in growing pigs if the DDGS is of good quality” thus reported Stein [12], 10 to 20% of the inclusion rate in monogastric diet without compromising the performance [5]. The maximum inclusion rate of corn DDGS in pig diets has been reported (Fig. 1). Generally, the quality of the source of DDGS can affect the rate of inclusion in the diet [25]. Therefore, there is limitation of DDGS in diet for swine, low digestibility of fiber and protein [36,12].

The results of the experiment conducted by Whitney & Shurson [37], suggest that high quality corn DDGS can be included in Phase 3 diets for nursery pigs (above 7kg) at dietary levels up to 25%, without negatively affecting growth performance after a two-week acclimation period [11]. In addition, if corn soybean diets are formulated on digestible amino acid and available phosphorus basis, 30% of DDGS will support growth performance in nursery, growing finishing and developing gilts pigs, however, it reduces belly firmness and helps to meet pork fat quality standards in growing finishing pigs [11]. “For sows, up to 50% DDGS can be successfully added to gestation diets, and 30% DDGS can be added to the lactation diet if DDGS is free of mycotoxins. However, a short adaptation period may be necessary when switching sows from a

Table 1. Average mean of distillers dried grains with solubles’ physical properties from dry ethanol plants

Physical Property	Mean[1]	Mean[2]
Moisture content, %	14.7	4.92
Water activity, -	0.55	0.48
Thermal conductivity, W/m°C	0.07	0.08
Thermal resistivity, m°C/W	14.0	-----
Thermal diffusivity, mm^2/s	0.13	0.14
Bulk density, kg/m^3	483.3	488.97
Angle of repose, °	31.5	33.29
Color, Hunter L*	43.1	42.46
Color, Hunter a*	8.7	13.41
Color, Hunter b*	19.4	18.45

L - reading (0 = dark, 100 =light), a* reading measures the redness of color and b* reading measures the yellowness of DDGS color; Source: Adapted data from [1]Rosentrater, [27] and [2]Bhadra et al. [28]*

Table 2. Good DDGS quality to obtain for pig diets

Item	Minimum %	Maximum %
Crude Protein	27.0	-
Fat	9.0	-
Phosphorous	0.55	-
Lysine	2.8	-
ADF	-	12.0
NDF	-	40.0

ADF -acid detergent fiber; NDF -neutral detergent fiber; Source: Adapted data from Stein [12]

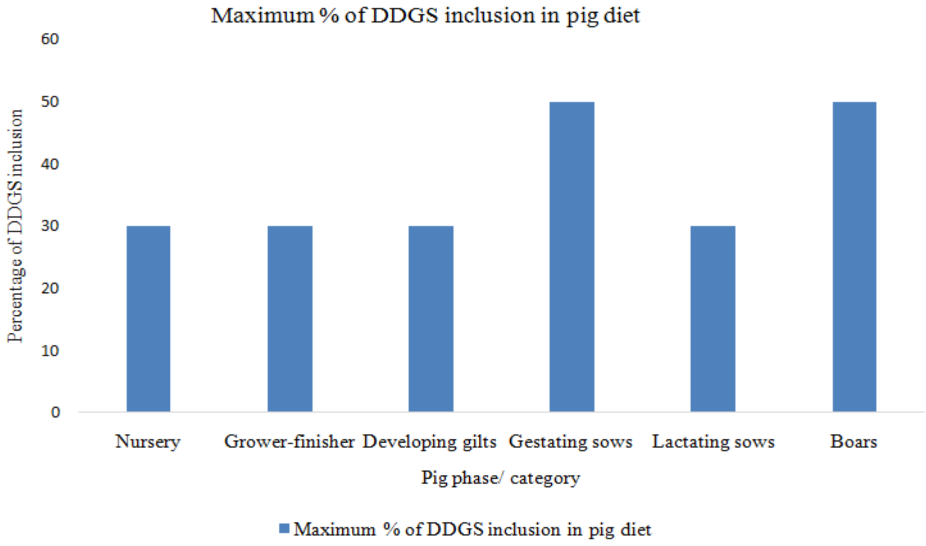

Fig. 1. The recommended maximum inclusion rate of DDGS in different pig phases
Source: Adapted data from Shurson et al., [11]

corn-soybean meal diet to diets containing high levels of DDGS in lactation" Shurson et al., [11]. These recommendations assume that high quality DDGS is free of mycotoxins [12,11]. On chapter 4, Table 3 also discloses certain effects of the inclusion rate of DDGS in pig categories' diet.

3.4 Production Process of Corn DDGS on Bioethanol Industries

Before any grain can enter a typical ethanol production plan, it is tested for quality assurance [4]. Samples are checked to see whether there is or no mycotoxin material and if found they are rejected [4]. This documentation helps to inform the level of mycotoxins for remedial actions [38,39]. Even though majority of ethanol production use corn [3], other processes use crops such as sorghum [10], barley [40,41], and wheat [8]. Processing techniques from ethanol industries can drastically affect the appearance, palatability, and nutrient composition of DDGS [1].

After the grain quality control process (Chapter 2.4), Fig. 2 illustrates, the corn is grinded to reduce the particle size which is required during the production process of DDGS on bioethanol industries. The grinded corn is added water for cooking stage, then follows liquefication where enzymes are added (23,8). From liquefication to saccharification yeast is added for fermentation, and after the fermentation process releases carbon dioxide and at the other side releases the distilled portion, where it releases ethanol, and the centrifuged part brings wet distillers' grains (WDG) that will later on mixed with condensed distillers' solubles (CDS) in the dryer to result the distillers dried grains with solubles and water p23]. After distillation, the remaining water and solids (fiber, protein, fat, non-fermented carbohydrates, and yeast biomass) are called whole stillage. The whole stillage is centrifuged to separate the coarse solids from the liquid, which is called thin stillage. Thin stillage is evaporated to remove water, resulting in condensed distillers' solubles (CDS), a syrup that has about 30% dry matter [29]. The mixing ratio of WDG and CDS can considerably affect the chemical composition of the DDGS [7,42].

3.5 Treatment of DDGS

3.5.1 Physical treatment

Physical treatment includes grinding, crushing, high temperature cooking as its ways of treatment [43,44]. With except of high temperature cooking, other method does not affect the chemical characteristics or composition of the feedstuff, but they are based on reducing the particle size, increasing the surface area, and exposing the internal components [43]. In addition, it facilitates the decomposition of microorganisms during the intestinal digestive tract whenever the feed is taken by the animal. However, the operation of this treatment method requires special equipment for processing, which increases the cost of production [45], also fine particle size causes flowability problems in bins and feeders which may probably harm the animal [46].

3.5.2 Chemical treatment methods

Chemical treatment methods involve dilute acid and alkali, where the feed crystallinity is reduced, the lignin and fiber are peeled away from each other to improve the utilization rate of feed [47]. These are types of chemical treatments; ammonia fiber expansion (AFEX), Liquid hot water (the so called autohydrolysis), dilute acid hydrolysis, and alkali pre-treatment, such as reviewed by Afroditi Chatzifragkou and others [48].

3.5.2.1 Dilute acid

Dilute acid treatment is one of the most important techniques for achieving high lignocellulose sugar yields. It is usually carried out with 0.2-2.5% w/w of acid between the range temperatures 130-210^0 C [49]. In 5 minutes at 180^0 C of temperature or with long period of time that is within 30 to 90 minutes at 120^0 C, the dilute acid pretreatment can be performed [50]. Mostly, sulfuric acid, hydrochloric, phosphoric, and nitric acids are the acids used, and these acids have been noted on hydrolyzing hemicellulose and cellulose [51].

3.5.2.2 Dilute alkali

Severe [low alkali concentrations (i.e., 0.5-4%) and high temperatures] or moderate conditions [high alkali concentration (i.e., 6-20%) and low temperatures (i.e., 0-30^0 C)] [52-55] are two pretreatment processes that can either performed on dilute alkali treatment. The alkali most commonly used are NaOH, ammonia, peroxide, and lime because of their low cost and effectiveness in lowering enzyme dosages subsequently required to convert cellulose to glucose [56]. This treatment method results in enriched fractions of cellulose and hemicellulose [57].

3.5.2.2.1 Ammonia fiber explosion

Ammonia fiber explosion (AFEX) falls in alkaline thermal pretreatment and it exposes biomass to liquid ammonia under high temperature and pressure, followed by a rapid pressure release [58]. Generally, moderate temperatures (i.e., 60-100^0 C) are used with ranging time of 5 to 30 minutes, and up to 1 kg of ammonia is added per kg of dry substrate [59,60,61], and ammonia is recovered and recycled in the process [62]. This pretreatment does not directly liberate sugars, but rather solubilizes lignin to permit more efficient hydrolysis of hemicellulose and cellulose during subsequent enzymatic saccharification [49,63]. This treatment does not produce inhibitors and small particle size is not needed for efficacy [64,57]. Unfortunately, this treatment is less efficient if the biomass has high lignin content and can cause solubilization of a small fraction of solid material, specifically hemicellulose [57]. The method has been reported to improve the efficiency of enzymatic hydrolysis on DDGS [65].

Generally, the chemical treatment method on itself is not environmentally friendly, besides being of high cost [66]. The feed pretreated by this method may have negative effects in animals, probably it may reduce the intestinal microorganisms (microbial accounts) that are responsible for digestion and results on unhealth digestive tract as an effect of acid and alkaline condition, which is not environment friendly in the gut. Another disadvantage of chemical treatment (dilute alkali) is that inhibitors can be generated from the lignin decomposition (phenols, carboxylic acids, and furans), causing economically unsustainable practices [67].

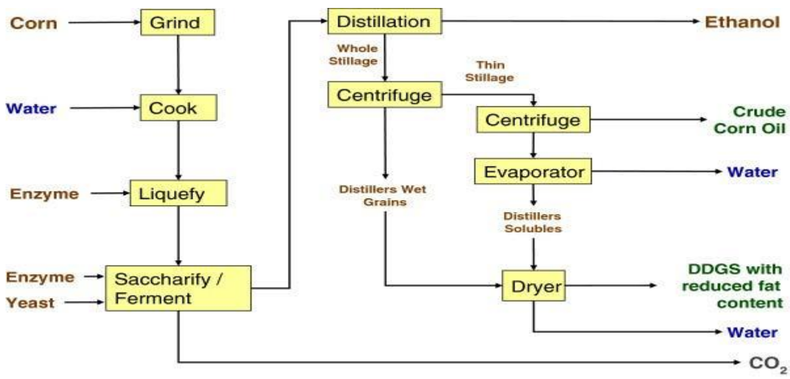

Fig. 2. Dry-grind ethanol and co-product production process
Source: Council [23]

3.5.3 Microorganism on feed treatment

Micro-organisms (probiotics) used as feed additives are of different microbial origin, animal digestive tract, soil, fruits, e.g., *Enterococcus faecium, Bacillus spp., Saccharomyces, cerevisiae* [68]. In addition, probiotics have been applied in human food, animal nutrition, pigs, however, the use of micro-organisms in feed differs considerably from that in human food [68]. They do not provide essential nutrients, but they have got potential advantages for health promotion [69,70,71].

3.5.4 Microbial treatment of DDGS

Recently, there are endless research on the use of microorganisms' enzymes to treat DDGS fiber. There are different types of treatment as previously resumed, physical (chapter 3.5.1), chemical (chapter 3.5.2) one, but not under this type, microbial/ enzymatic treatment. The chemical is not environmentally friendly in the pig gut, beside of being not economical, yet the biological treatment is found to be environmental friendly, economical [66], and is mainly to add microbial or enzymes preparations which improves the nutritional value by controlling factors such as pH that inhibits the harmful bacteria, temperature, and period to breakdown the corn DDGS components as a pretreatment way to facilitate the pig digestion process whenever fed DDGS [72,71].

With the development of bioengineering technology, enzymes or proteases have been used on hydrolysis as a strategy to improve the nutritive value of feed for pigs [73,74].

3.6 Effects of Treated corn Distillers Dried Grains with Soluble (DDGS) on Pigs

Distilled Dried Grains with Solubles feed value may be improved by fermentation using enzymes [75]. Table 3 illustrates the contribution of enzymes on DDGS as a dietary supplement fed to different categories of pigs. In wheat diet, corn DDGS treated by the combination of phytase, and xylanase fed to growers had no improvement on nutrient digestibility [76]. In corn, soybean growing finishing pigs diet, corn DDGS it had no improvement ($P > 0.10$) in ADG, ADFI, and G:F between pigs fed diets with added enzyme and pigs fed diets without enzyme) [77]. Their experiment [77] showed that the commercial enzymes studied had no effect on the improvement utilization of nutrients from DDGS based ingredients. The increase of dry matter, crude protein and energy digestibility was noted for grower and finisher's diet [78] and for nursery [79]. In addition, the gilt growth performance improved, and barrows decreased for growers and finishers, and the feed efficiency increased whilst the growth decreased for nursery. All the data shows that each enzyme has a certain level of positive influence in corn distilled dried grains with soluble fed to different phases of pigs. In other words, distilled dried grains with soluble can be improved by enzymes.

4. EFFECTS OF CORN DDGS ON THE PERFORMANCE AND HEALTH STATUS OF PIGS

It has been reported from different scientific research works that, corn DDGS has a positive effect when included in diets on recommended levels on pig growth. From the work review done by Stein and Shurson [25], the results showed that there was no change on average daily gain (ADG), average feed intake (ADFI), gain feed (G:F) ratios on more than 60% of growing-finishing experiments which had conducted, and the rest which is around less than 40% had shown either increases or decreases in performance. Based on these reported results of lesser performance than the expected, it may be due to the DDGS nutrient value that was used to formulate the experimental diet, and it was noted that the crude protein in these diets was high which may also be one of the reason behind, because pigs may not be able to digest well the nutrients and they end up by releasing a lot of nitrogen, which reflects exactly poor pig performance. And the diet palatability influenced the reduced feed intake, and it affected the daily gain by the reason of diet with poor DDGS' quality [25].

The inclusion of 20% DDGS in young growing pig diet reduced ADFI, ADG, and G:F by 25, 55, and 40%, respectively, during the 3-week post-challenge period [80]. In addition, it did not affect growth performance, and also did not positively affect lesion prevalence and length, proliferation of *L. intracellularis*, or severity of lesions. On another experiment which Whitney and others conducted, diet with 10% DDGS reduced ileum and colon lesion length and prevalence and reduced the severity of lesions in the ileum and colon [81]. The reason behind the difference results on those two experiments, might be of DDGS percentages included in diet.

Table 3. Effects of treated corn DDGS on the nutrient digestibility and performance of pigs

Diet fed	NSP enzyme	Pig phase	Nutrient digestibility	Performance	Source/ reference
Wheat and Corn-DDGS	Phytase, xylanase	Grower	↕ energy digestibility	------	[76]
Corn, SBM, corn DDGS	B-glucanase, Xylanase, protease, mannanase	Grower- finisher	Not verified	↕ on studies	[77]
Wheat, barley, corn, SBM, CM, corn DDGS, wheat middling, rye	Xylanase and β-glucanase	Grower-finisher	↑ DM, CP, and energy digestibility	↑ gilt growth performance, ↓ b barrows	[78]
Corn, SBM, Corn or sorghum DDGS	Xylanase, alfa-amylase, beta-glucanase and protease	Nursery	↑ DM, ↓ CP and energy	↑ Feed efficiency, ↓ growth	[79]

Note: ↕ - No improvement; ↑ - increase/ improvement; ↓ - decrease; DDGS- distillers dried grains with soluble; CP- crude protein; DM- dry matter

Youngji Rho et al. [75] investigated the effects of fermenting corn DDGS with a blend of β-glucanase and xylanases (XB) on growth performance, gut parameters, and apparent total tract digestibility (ATTD) of nutrients and energy, in growing pigs in two phases feeding program (each three weeks per phase). Dietary treatments were: (1) corn soybean meal-based diet + 30% DDGS (control), (2) control + XB without fermentation (XBNS), and (3) control + DDGS fermented with XB (16% dry matter) for 3 to 10 d at 40°C (XBS). There were no diet effects ($P > 0.05$) on feed conversion ratio in phase 2 or in the overall. Pigs fed DDGS with XBNS had lower ($P < 0.01$) ATTD of crude protein than control and XBS-fed pigs. Although not different ($P > 0.05$) from control, pigs fed DDGS with XBNS had lower ($P < 0.05$) jejunal crypt depth and ATTD of gross energy than pigs fed DDGS with XBS. In addition, the authors concluded that treated corn DDGS improved feed efficiency, though it was associated xylanase. In young pigs it was noted that, corn DDGS (0 or 30%) could not affect the average daily gain [82], which coincided with the suggestion given by Youngji Rho et al. [75] that says, there may be a limit of nutrient utilization on the same age of pigs, when dietary fiber components are reduced in size (degradation).

The effects of corn DDGS on health status indicators in weanling pigs have been studied [83]. No effects of dietary treatment were observed for serum immunoglobulin in experiment. Fecal microbial profiling resulted in statistically significant effects of dietary treatment with respect to microbial similarity and diversity indices (Experiment 1) and lactic acid-producing bacteria (Experiment 2), where main effects of DDGS were observed with respect to putative *Lactobacillus reuteri* [$P < 0.05$). Results from Experiment 1 indicate that decreased concentrations of DDGS early in the nursery phase may negatively affect growth performance; however, growth performance may be maintained when inclusion of high concentrations (30%) of DDGS is delayed until the late nursery period.

Jerry Shurson [46] on the work titled Benefits and limitation of using DDGS in swine diets resumed that, high levels of DDGS (more than 20%) on growing finishers diets may reduce pork fat quality and the author went furthermore confirming that DDGS appears to reduce gut health problems to ileitis. This ended up by coinciding with what was reviewed [84], that fermented feed has a positive impact on health.

5. CONCLUSION

There are many ways of treating DDGS in order to feed pigs, but the microbial one and/or sometimes combined with some methods of physical treatments can improve its feed value for a nice environment and friendly for pig gastrointestinal tract. A lot of research conducted about its treatment, focused on improving fiber content. However, there is still a gap opened on work research needed about improving the protein content in order to include DDGS in monogastric (pig) diets in high quantities, as much as possible. Majority of DDGS produced comes from corn grain. Normally, corn DDGS is fed with the addition of enzymes.

Recommended percentages of the inclusion of DDGS in pig diet is based on digestible amino acids and it goes on according to pig phase and or category to achieve good performance.

Treated corn DDGS increases feed intake, gain weight, and it also improves nutrient digestibility and the health status of pigs, whilst is taken into consideration of the DDGS with absence of undesired levels of mycotoxins.

Since the feeding cost of pig production is high, further investigations are still required to optimize corn DDGS content using simple or combination of microorganisms (bacteria or fungi), and to increase corn DDGS levels, whilst reducing corn-soybean meal in pig diet.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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