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Influence of different inclusion levels of corn dried distillers grains with solubles (DDGS) in the diet of growing pigs on the digestibility of nutrients

Gancho Ganchev[1], Atanas Ilchev[1] and Krum Nedelkov[2]

[1] *Trakia University, Faculty of Agriculture, 6000 Stara Zagora, Bulgaria*
[2] *Trakia University, Faculty of Veterinary Medicine, 6000 Stara Zagora, Bulgaria*
* *Corresponding author:* glen62@abv.bg

Abstract

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The objective of this study was to determine the total tract digestibility coefficients of growing pigs fed diets with different inclusion levels of corn dried distillers grains with solubles (DDGS) produced in Bulgaria. Four castrated male pigs from the Danube White breed with an average body weight of 16 ± 0.3 kg, housed in individual metabolic cages, were used in the digestibility experiment. Four different diets were examined: 1) a basal diet (100 corn), consisting mainly of corn, (96.25% corn and 3.75% vitamins and minerals); 2) 60/40 DDGS diet, in which DDGS was included at 40%; 3) 40/60 DDGS diet, in which DDGS was included at 60%, and 4) DDGS based diet (100 DDGS), consisting mainly of corn DDGS (97.5% DDGS and 2.5% vitamins and minerals). The apparent total tract digestibility coefficients of dry matter (DM), crude protein (CP), ether extracts (EE), crude fibers (CF), and nitrogen free extract (NFE) were determined. Increasing the inclusion level of DDGS in the rations of growing pigs significantly reduced the digestibility coefficients of the main nutrients - CP, EE, and NFE, but did not affect the digestibility of CF.

Keywords: corn; corn DDGS; digestibility; growing pigs

Abbreviations: DDGS – dried distillers grains with solubles, CF – crude fibre, CP – crude protein, EE – ether extract, NFE – nitrogen free extract

Introduction

Wheat and corn are the main cereals used for the production of ethanol in our country. The DDGS obtained from the two raw materials does not differ significantly in nutrient composition. The protein, fat and fiber content are approximately 3 times higher and the energy content (DE) is close to that of the raw materials (Widyaratne & Zijlstra, 2007; Stein & Shurson, 2009). This makes DDGS an ideal candidate for an alternative source of energy and protein in pig rations, by the use of which feed cost may be significantly reduced (Zijlstra & Beltranena, 2013; Woyengo et al., 2014). However, the higher crude fiber content limits the use of DDGS because of the fibers' negative effects on the digestibility of energy and protein (Thacker, 2006; Avelar et al., 2010). In addition, a number of studies have found very wide variation in composition (Liu, 2011; Liu & Rosentrater, 2012; Anderson et al., 2012; Li et al., 2015) and nutrient digestibility in different batches of DDGS from one and the same raw material (Stein et al., 2006, 2007; Pahm et al., 2008; Li et al., 2016; Wang et al., 2016). As a result, quite contradictory results from the use of DDGS in pig farming have been published so far, especially about growing pigs. The digestibility of most of the amino acids in DDGS is lower than the digestibility of the grains from which it was produced, probably due to the higher crude fiber content. The greatest is this variation in digestibility of lysine (Fastinger & Mahan, 2006; Cozannet et al., 2010, Rosenfelder et al., 2013), which in most cases is due to the thermal damage during the production of DDGS (Pahm et al., 2008; Almeida, et al., 2013). Studies using different amounts of DDGS in swine rations have been shown contradictory results. In some experiments, it has been observed that the use of up to 30% (Augspurger et al., 2008; Widmer et al., 2008; Woyengo et al., 2016; Wu et al., 2016; Curry et al., 2019) and even 60% DDGS in rations (Weber et al., 2013) did not lead to any differences in average daily growth, feed consumption and feed consumption per unit of growth. Others reported a decrease in growth (Whitney et al., 2006; Linneen et al., 2008; Weimer et al., 2008; Kanev et al., 2016; Wang et al., 2016) and reduction of feed consumption (Linneen et al., 2008; Avelar et al., 2010; Graham et al., 2014a) by increasing the amount of DDGS in the rations from 10 to 20 or 30%, and this is particularly pronounced when the amount of DDGS was increased to 35% (Clarke et al., 2018), to 40% (Stend-

er & Honeyman, 2008) or to 60% (Hardman, 2013).

Furthermore, in a few more studies even more divergent results were stated whereby increasing the amount of DDGS in the rations it was observed - an increase of daily growth but also feed consumption (Gowans et al., 2007), reducing of feed consumption without affecting daily growth (Xu et al., 2010) or reducing daily growth while maintaining feed consumption and expenditure (Cromwell et al., 2011).

Based on the available data, it is difficult to draw definitive conclusions about the influence of different amounts of DDGS in the rations of growing pigs. The aim of this study was to investigate the effects of different DDGS levels in the ration of growing pigs on feed consumption and total tract nutrient digestibility.

Materials and Methods

The animal experiment was conducted in the Swine Research Center at the Faculty of Agriculture, Trakia University. Four castrated male pigs from the Danube White breed with initial body weight of 16 ± 0.3 kg and final body weight of 31 ± 0.4 kg, housed in individual metabolic cages, were used in the digestibility experiment. Each experiment included a 5-day preliminary/adaptation and a 5-day trial period during which feces were collected. Four different diets were examined: 1) a basal diet (100 corn), consisting mainly of corn (96.25% corn and 3.75% vitamins and minerals); 2) 60/40 DDGS diet, in which DDGS was included at 40%; 3) 40/60 DDGS diet, in which DDGS was included at 60% and 4) DDGS based diet (100 DDGS), consisting mainly of corn DDGS (97.5% DDGS and 2.5% vitamins and minerals). Diets were formulated using corn, corn DDGS, limestone and other vitamin/mineral supplements (Table 1) to meet or exceed the nutrient requirements for growing pigs (based on NRC, 2012). The chemical composition of the feed used is shown in Table. 2

Table 1. Composition and nutritional value of dietary treatments (% or as indicated)

Items	Diets			
	1	2	3	4
	100 Corn	60/40 DDGS	40/60 DDGS	100 DDGS
Corn %	96.25	58.32	39	-
DDGS %	-	38.88	58.55	97.5
Limestone %	0.75	1.5	1.8	2
Dicalcium phosphate %	2.2	0.8	0.15	-
Salt %	0.3	-		-
Vitamin premix %	0.5	0.5	0.5	0.5
1 kg compound feed contains				
DE MJ/kg	14.5	13.1	12.3	10.7
CP %	8.9	14.4	17.2	22.8
CF %	2	5	6.4	9.4
Ca %	0.8	0.82	0.82	0.82
P available %	0.32	0.32	0.32	0.46
Digestble amino acids, %				
Lysine	0.18	0.24	0.26	0.31
Methionine+Cystin	0.33	0.42	0.47	0.56
Threonine	0.27	0.35	0.39	0.47
Tryptophan	0.05	0.04	0.03	0.02

Table 2. Chemical composition of diets fed to growing pigs (g/kg DM)

Items	DM	CP	EE	CF	NFE
100 Corn	898.7	92.5	43.9	21.1	826.5
60/40 DDGS	895.7	148.7	57.6	51	703.1
40/60 DDGS	894.2	176.7	64.4	65.9	641.5
Corn DDGS	891.2	232.9	78.1	95.8	518.1

During the adaptation periods, the animals were fed *ad libitum* in order to specify the consumption. After completion, the required amount of feed was weighed for each day of the trial periods. The pigs had free access to fresh potable water and were fed twice daily at 08:30 h and 16:30 h. The refusals were collected each morning before feeding and stored in individual plastic bags.

Fecal collection during the trial period was carried out in the morning before feeding the animals. A sample of 10% of the total amount was taken for analysis daily after homogenization. Fecal samples were oven dried at 65°C for 48 h, ground through a 1-mm sieve in a Wiley mill (Thomas Scientific), homogenized and saved in sealed plastic bags for further analyses.

All dried samples were analyzed by wet chemistry methods for CP (method 990.03; AOAC International, 2000), ether extract (EE, method 2003.05; AOAC, 2006), crude fiber (method 962.09; AOAC) and minerals (method 985.01; AOAC, 2000) (Table 1).

The apparent total tract digestibility was calculated as a difference of consumed nutrients and nutrients excreted with feces.

Data were analyzed for the fixed effect of different DDGS levels using STATISTICA 10 for Windows (2010). Significance was declared at $P < 0.05$.

Results and Discussion

Approximately two-thirds of corn grain is starch and 60-70% of it is converted to ethanol and carbon dioxide during the fermentation process (Woyengo et al., 2016). Therefore, the by-products of ethanol production have lower starch content, but approximately 3 times higher content of crude protein, crude fat and crude fiber (Widyaratne & Zijlstra, 2007; Stein & Shurson, 2009). This makes DDGS a good source of protein, fat and minerals in the pig's ration. However, the high fiber content in DDGS reduced not only their digestibility, but also the digestibility of DM, other nutrients and energy (Urriola & Stein., 2010), which led to a reduction in feed consumption and also increased fecal excretion.

Table 3. Dietary intake and fecal excretion

Items	Diets			
	1	2	3	4
	100 Corn	60/40 DDGS	40/60 DDGS	100 DDGS
Intake feed, g/day	784.38 ± 30.66^{abcd}	673.75 ± 24.36^{b}	679.75 ± 40.60^{c}	634.50 ± 38.89^{b}
Intake DM, g/day	704.93 ± 27.55^{abcd}	604.29 ± 21.85^{b}	609.46 ± 36.38^{c}	567.71 ± 38.85^{d}
Fecal, g/day	367.50 ± 17.74^{acd}	374.50 ± 22.43^{bd}	532.25 ± 35.31^{cbd}	620.00 ± 40.30^{d}
Fecal DM, g/day	109.91 ± 5.70^{acd}	113.70 ± 6.30^{bd}	158.23 ± 10.97^{cbd}	185.90 ± 10.75^{d}

a,b,c,d – Means within a row lacking a common superscript differ significantly at $P < 0.05$

The data for feed and water consumption, and the amount of excreted feces are indicated at Table 3. Food consumption was about 20% higher when a basal diet (consisting mainly of corn) was fed as compared to DDGS diets. Mixing the two raw materials in different proportions resulted in an increase of daily consumption by 6-7% compared to 100 DDGS ration, but it still remained about 15% lower than the consumption of the basal diet. This is probably due to the higher amount of crude fiber in DDGS rations, as the increased fiber content may limit the physical ability of the intestine to digest more food (Wu et al., 2016). Similar results of reduced consumption have been found in a number of other studies (Linneen et al., 2008; Avelar et al., 2010; Hardman, 2013; Graham et al., 2014a; Clarke et al., 2018). However, Cromwell et al. (2011), Weber et al. (2013) and Curry et al. (2019) did not observe any effect on feed intake when increasing levels of DDGS were included in the rations of growing pigs.

Feeding high-fiber diets increased the amount of feces excreted (Hansen et al., 2007) and the amount of DM excreted with feces (Wilfart et al., 2007). The high levels of insoluble fiber (ADF) in the diets increased the passage rate through the gastrointestinal tract. As a result of fermentation during the production of bioethanol, products with a high content of difficult-to-ferment fiber are obtained (Jha et al., 2015). The use of these products in pig rations was found to decrease the DM digestibility and also to increase the amount of feces excreted (Widyaratne & Zijlstra, 2007; Pedersen & Lindberg, 2010; Urriola et al., 2010, Thacker, 2012). In our study, we noticed the same trend of a significant increase in the amount of feces excreted when the inclusion level of DDGS in the rations was gradually increased. The observed increase was about 2 and 45% for the 40 and 60 DDGS rations, respectively, compared to the basal diet. In a 100 DDGS diet the amount of excreted feces was 69% higher compared with the ration which consisted mainly of corn. The increase in the amount of feces excreted with an increase in the diets' fiber content was a result on one hand of the higher water retention capacity of soluble fibers (Serena et al., 2008), and on the other of the increased amount of insoluble fiber, as 50% to 60 % of DM in the rectum are insoluble fibers (Wilfart et al., 2007). The results

for determining the apparent total tract digestibility of nutrients are shown in Table 4. The data showed significant differences in most of the studied indicators. The general trend was that with increasing amounts of DDGS in the ration the digestibility coefficients of the essential nutrients decreased significantly.

In the case of DM, this reduction was 20% between singly fed raw materials (corn and DDGS). These results perfectly matched the data for the amount of feces excreted. When the inclusion level of DDGS in the ration was increased to 40 and 60%, the DM digestibility was decreased by 4 and 12%, respectively (Table 4). The decreased extent of DM digestibility as a result of an increased DDGS diet level was also found in studies conducted by Agyekum et al. (2016), Li et al. (2016), and Corassa et al. (2017).

The main advantage of DDGS as a feed source is its high protein content. In this regard, the digestibility of the protein is essential for the effectiveness of the use of DDGS in pig farming. However, the protein digestibility is directly related to the fiber content. The high fiber content enlarged the excretion of nitrogen with feces (Bindelle et al., 2009) and decreased the digestibility of the protein (Wilfart et al., 2007; Urriola & Stein, 2012). We found that dietary concentrations of DDGS up to 40% did not significantly affect the CP digestibility. These data were supported by the results of Pedersen et al. (2007) who tested rations with 50% dietary level of different batches of DDGS and Corassa et al. (2017) with the inclusion of DDGS in the ration amounted to 40 and even 60%. However, inclusion of 60% DDGS in the diet was found to decrease the CP digestibility by 7.5%. Others reported a reduction in the CP digestibility even with lower DDGS dietary inclusion levels. According to Wang et al. (2016) the CP apparent digestibility was linearly reduced with an increase of DDGS from 0 to 20%, Wahlstrom et al. (2013) and Corassa et al. (2019) reported levels above 20%, and Agyekum et al. (2016) at 30% DDGS in the diet. The lower CP digestibility may be explained by increased endogenous secretion, decreased hydrolysis and absorption of nutrients or both (Wilfart et al., 2007). Our results showed a 13% lower digestibility of DDGS CP compared to corn based diets. According to Liu et al. (2012) and Graham et al. (2014a), however, the higher fiber content of DDGS did not affect the digestibility of DDGS CP compared to corn.

The other advantage of DDGS is the relatively high fat content - between 6 and 8% on a DM basis. The results of the current experiment revealed that the EE digestibility was decreased about 9% in the rations containing 40% and 60% DDGS, and by 12% in 100 DDGS diet compared to the ration based mainly on corn. In our study the digestibility of EE was not different between the rations containing increasing levels of DDGS. Corassa et al. (2017) also found no differences in EE digestibility between rations with 40 and 60% DDGS dietary concentrations. In another study by Corassa et al. (2019), however, a decrease in the EE digestibility with an increasing level of DDGS in the ration from 20 to 40% was reported. Agyekum et al. (2016), observed a tendency of an increased EE digestibility when DDGS in the ration amounted to 30%. Kerr et al. (2015) also reported an increase in the EE digestibility with an increase in dietary level of DDGS to 10, 20 and 30%, but according to the authors that was due to the larger amounts of soybean oil added to the rations for balancing energy. According to Graham et al. (2014b) the EE digestibility of the diet also appeared to depend on the fat content of the DDGS used.

Table 4. Apparent total tract digestibility coefficients

Items	Diets			
	1	2	3	4
	100 Corn	60/40 DDGS	40/60 DDGS	100 DDGS
DM	84.44 ± 0.43^{abcd}	80.99 ± 1.18^{bcd}	74.26 ± 0.97^{cd}	67.35 ± 0.66^{d}
CP	78.78 ± 0.13^{acd}	78.02 ± 1.03^{bd}	72.88 ± 0.68^{cbd}	68.24 ± 0.34^{d}
EE	74.07 ± 0.50^{abcd}	67.17 ± 1.49^{b}	67.67 ± 0.52^{cd}	65.54 ± 0.52^{d}
CF	38.83 ± 2.20^{ab}	44.94 ± 1.04^{bd}	39.13 ± 1.20^{cb}	36.61 ± 0.66^{d}
NFE	93.02 ± 0.33^{abcd}	87.41 ± 1.21^{bcd}	80.14 ± 1.14^{cd}	75.85 ± 1.23^{d}

a,b,c,d – Means within a row lacking a common superscript differ significantly at $P < 0.05$

The high fiber content of DDGS reduced the fiber digestibility in the whole digestive tract, which also affected the digestibility of DM and other nutrients (Urriola & Stein, 2010). The fibers in DDGS are mainly insoluble due to the high content of insoluble arabinoxylans, cellulose and lignin (Pedersen et al., 2014) and are resistant to fermentation in the colon (Urriola et al., 2010; Jha et al., 2015).

According to Urriola et al. (2010) less than 50% of the total amount of fiber in DDGS passes through the gastrointestinal tract of pigs without being fermented while only 18% of the NDF are fermented in the large intestine (Gutierrez et al., 2014). Increasing the dietary inclusion level of DDGS would increase the amount of fibers in the diet due to the higher fiber content in DDGS, and would lead to a decreased fiber digestibility. This is confirmed by the results obtained by Agyekum et al. (2016), Corassa et al., (2017), Corassa et al., (2019) who reported a decrease in the fibers digestibility in diets with different inclusion levels of DDGS. The crude fiber digestibility coefficient of corn based diet was 38.83%. Accordingly, the inclusion of 40% DDGS in the ration resulted in an increase in the CF digestibility coefficients to about 45%. A linear increase in the fibers digestibility of the diet was also observed by Agyekum et al. (2014) with an increase in the amount of DDGS from 0 to 30%.

We assume that this may be due to the processing of corn during the production of ethanol (grinding, heating, fermentation), which may alter the structure of the fibers, mainly under the action of enzymes released by microorganisms, leading to the partial breaking of the bonds in the carbohydrate-lignin complex, and also increase their digestibility compared to the digestibility of the fibers in corn. Increasing the inclusion level of DDGS to 60%, however, reduced the CF digestibility to 39.13% as much as was the digestibility of corn fed singly in the basal diet.

There are significant differences in the digestibility coefficients of NFE. Corn is characterized by high NFE digestibility. The inclusion of DDGS reduced the digestibility by 6-18% depending on its dietary concentrations. We assumed that the observed decrease was mainly because of the increased level of crude fibers.

Conclusions

By increasing the inclusion level of DDGS in the diets of Danube White growing pigs the feed consumption was reduced and the amount of feces excreted was increased.

Increasing the inclusion level of DDGS in the rations of growing pigs reduced the digestibility coefficients of the main nutrients - CP, EE, and NFE, but did not affect CF digestibility.

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