

Original Research Paper

Evaluation of Fibrous Diets for Finishing Pigs: Digestibility, Performance and Carcass Traits

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Abstract: Two experiments were conducted to evaluate digestibility, performance and carcass traits of finishing pigs fed fibrous diets, such as, basal diet (Control treatment) and inclusion of Tifton-85 hay, Soybean hulls or Citrus pulp. Twenty crossbred castrated male pigs, with average body weight of 70.00±1.95 kg, distributed in a randomized block design with four treatments and five repetitions (blocks) were used to evaluate apparent total tract digestibility of dietary nutrients. To evaluate animal performance and carcass traits, eighty commercial hybrids pigs with 120 days of age and average body weight of 73.00±3.3 kg were used. Pigs were distributed in 40 boxes according to gender and body weight, with one castrated male and one female pig per pen (experimental unit), in a randomized block design with 10 repetitions (blocks) per treatment were used. Regarding the digestibility assay, Tifton hay presented 2425 kcal of digestible energy/kg, with low digestible protein content (3.36%). Citrus pulp presented 2850 kcal of digestible energy/kg, also with low digestible protein content (1.47%). Soybean hulls showed 2250 kcal of digestible energy/kg, with relatively medium crude protein digestibility coefficient (7.85%). Offering different fiber sources in the finishing phase for pigs promoted significant differences ($p<0.05$) in animal performance parameters (daily weight gain, daily feed intake and feed conversion) and no significant effect ($p>0.05$) was observed for carcass parameters. Given the results obtained in this study, Soybean hull showed to be a promising ingredient to be used in diets of finishing pigs, leading to good results on animal performance and also contributing to the sustainability of pig production.

Keywords: Tifton Hay, Soybean Hulls, Citric Pulp

Introduction

World pig production, like other agribusiness, has grown significantly in recent years. Given this growth, an extremely important factor is the degree of nutritional competition that pigs present in relation to the human species. Approximately 75% of raw materials used directly in human nutrition are also designed for this species (Ludke, 2000). Based on that, it is clearly necessary to reformulate nutrition and feeding system for pigs. This can be done through studies to investigate the ability of these animals to use alternative sources of energy and/or protein, which are preferably not used in human diet and are generally available at a lower cost to the producers, which is the case of several fibrous feeds.

The possibility of using forages and grasses in pig nutrition has been theorized by Carroll (1936). However, studies on the potential of various fibrous sources on swine production regarding the identification, quantification and evaluation of interactions between the physiological and associative effects on digestibility and animal performance are needed, given the limited ability of the digestive tract of these animals to process this fibrous feedstuff.

The dietary fiber term is directly related to plant cell wall components i.e., structural carbohydrates such as cellulose, hemicellulose, pectin and lignin (Mertens, 1992), that are degraded into short chain fatty acids during the process of enteric fermentation in the large

intestine (Gomes *et al.*, 1994), accounting for 30% of the energy requirements for animal maintenance (Kennelly *et al.*, 1981; Rerat *et al.*, 1987).

The purposes of this study are as follows: (1) To determine the nutrient apparent digestibility of different fibrous sources (Tifton-85 hay, Soybean hulls and Citrus pulp) for finishing pigs (Experiment 1); (2) to evaluate growth performance and carcass traits of finishing pigs fed with different fibrous sources (Experiment 2).

Materials and Methods

Experiment 1 - Apparent Total Tract Digestibility (ATTD) Assay

This study was conducted in the facilities of the Animal Nutrition Laboratory, of the Center for Nuclear Energy in Agriculture of the University of São Paulo, Piracicaba, São Paulo, Brazil (LANA-CENA/USP). In a 12 day experimental period (7 days of adaptation to diets and cages and 5 days of collection) 20 crossbred (Landrace × Large White × Pietrain) castrated male pigs, averaging 70.0±1.2 kg of Body Weight (BW) were used in an experiment to determine the Apparent Total Tract Digestibility (ATTD) of each fibrous source. Animals (experimental unit) were distributed in four treatments with five replications each in a completely randomized block design. They were individually allocated in metabolic cages, which allowed the separate collection of urine and feces, as described by Pekas (1968).

Pigs were fed a reference diet which was formulated according to Rostagno *et al.* (2011). Dry matter (DM), Crude Protein (CP) and Gross Energy (GE) analyses of diets were performed according to Silva and Queiroz (2002). Neutral Detergent Fiber (NDF) was determined according to Mertens (1992), Acid Detergent Fiber (ADF) and Lignin (LIG) were sequentially determined following the methodology proposed by Van Soest *et al.* (1991). By the difference between NDF, ADF and LIG, Hemicellulose (HEMI) and Cellulose (CEL) were calculated.

Treatments were formulated according to the fibrous ingredient employed as a 20% replacement of the reference diet (i.e., Citrus pulp, Soybean hulls or Tifton-85 hay). Diets were offered twice a day (08:00 and 16:00) according to metabolic Body Weight (BW^{0.75}) of animals and moistened in a 1:1 water and food ratio. Ferric oxide (Fe₂O₃) was added to the diets as a marker to indicate the beginning and end of the fecal collection and determination of ATTD was performed using the total feces and urine method.

From the Average Feed Intake (AFI) observed in the adaptation period, the Amount of Restricted Feed (ARF) was established and employed in the days of excreta collection, according to the following calculations:

$$ARF = I \times \text{Metabolic Body Weight}$$

where, ARF = amount restricted feed (kg); I = Index = AFI (kg)/Metabolic Body Weight; Metabolic Body Weight (kg) = BW^{0.75}.

The index (I) was calculated for all animals, however, the lowest I value was adopted to calculate the ARF.

Despite I value standardization, ARF were individually calculated according to each animal weight.

Urine was daily collected in plastic buckets, filtered in cheesecloth then total volume was measured and a 20% sample was stored under refrigeration at -20°C. In each bucket used for urine collection, 20 mL of 1:1 solution of hydrochloric acid and distilled water was added to prevent microbial growth and nitrogen volatilization. The GE and nitrogen analyzes were performed on urine samples and nitrogen balance, metabolizable energy and energy metabolism coefficient were calculated according to the methodology proposed by Adeola (2001). Excreta samples from the rectum of the animals were collected twice daily and immediately placed in plastic bags, identified and frozen at -20°C. After, these samples were thawed under ambient conditions and homogenized into a single composite sample. Then samples were dried in forced air circulation ovens at 65°C 88 for 72 h and ground in a Willey mill to pass through a 1 mm sieve followed by DM, GE, CP, NDF and ADF analysis (Silva and Queiroz, 2002). In addition, the apparent Digestibility Coefficients (DC) of DM, GE, CP, NDF and ADF and were calculated as well as the digestible nutrients of diets.

Experiment 2 - Growth Performance and Carcass Traits

Animals and Housing

The experiment was carried out on a commercial operation (St. Peter Pig Farm, Cordeirópolis, São Paulo, Brazil). The pigs were housed in 4 m² pens with partially slatted concrete floor, single spaced semiautomatic feeder and a nipple drinker in a naturally ventilated building. Feed and water were provided *ad libitum* to pigs throughout the entire 30 days growth study. Before starting the experiment, all animals were transferred to the finishing phase facilities where they received a basal diet for 1 week. Eighty crossbred (Landrace × Large White × Pietrain) pigs, averaging 73.0±3.3 kg BW and 120 days of age were distributed into 4 treatments with 6 replicate pens, with 1 castrated male and 1 female per pen in a completely randomized block design.

Treatments

The dietary treatments consisted of a corn-soybean meal basal diet (control treatment) and inclusion of fibrous sources (Tifton-85 hay, Soybean hulls, Citrus pulp; Table 2). The isoproteic and isoenergetic diets were formulated based on the nutrient requirements of finishing pigs (Rostagno *et al.*, 2011). Diets were formulated with

different fiber sources aiming an NDF content increase of 8%, considered as optimal by Gomes (2006).

Growth Performance and Carcass Traits Evaluation

Individual pig BW and pen feed disappearance were recorded at 7 d intervals during the experimental period to determine Average Daily Gain (ADG), Average Daily Feed Intake (ADFI) and Feed Conversion Ratio (FCR). In the end of 30 d growth study, 1 pig per experimental unit (3 males and 3 females/treatment) were slaughtered, scalded, de-haired and eviscerated. Immediately after evisceration, carcasses were weighed to calculate Hot Carcass Yield (HCY) then split longitudinally for the measurements of Carcass Length (CL), Backfat Thickness (BT), Loin Eye Area (LEA) and Fat-to-Meat ratio (F/M) according to the Brazilian Method for Carcass Evaluation (ABCS, 1973).

Statistical Analysis

The experimental design was a completely randomized block design with four treatments and ten repetitions per treatment. Statistical analysis of the data

was performed using the SAS® v.9.2 program (Statistical Analysis System Institute, Cary NC, USA). SAS LAB was used to verify the adequacy of the data to the linear model. Analysis of variance was performed using the GLM procedure and means were compared by Tukey test, adopting a 5% significance level.

Results

The results of chemical composition, gross energy content, DC and DN of the different fibrous sources fed to finishing pigs are present in Table 1. Tifton hay presented 2425 kcal of digestible energy/kg, with low digestible CP (3.36%). It also showed 28.47 and 22.63% of digestible NDF and ADF, respectively. Citrus pulp presented 2850 kcal of digestible energy/kg, but low digestible CP (1.47%). As for digestible NDF and ADF, values of 8.14 and 7.85% were observed, respectively. Soybean hulls introduced 2250 kcal of digestible energy/kg, with high digestible protein with contents of CP (7.85%), due to the relatively high digestibility coefficient.

Table 1: Chemical composition, gross energy content, apparent digestibility coefficients (DC) and digestible nutrients (DN) of different fibrous sources fed to finishing pigs

Parameters	Chemical composition			Digestibility Coefficients			Digestible Nutrients		
	Tifton hay	Cytric pulp	Soybean hull	Tifton hay	Cytric pulp	Soybean hull	Tifton hay	Cytric pulp	Soybean hull
DM (%)	93.90	90.19	91.32	65.00	89.10	55.63	61.06	80.35	50.80
GE (kcal/kg)	3984.06	3650.00	3900.00	67.26	70.75	57.69	2425.78	2850.00	2250.00
CP (%)	5.21	10.48	10.72	64.55	14.00	73.20	3.36	1.47	7.85
NDF (%)	74.67	20.86	68.09	38.00	39.00	31.87	28.47	8.14	21.70
ADF (%)	45.28	17.44	50.89	50.00	45.00	51.86	22.63	7.85	26.39

DM – Dry Matter; GE – Gross Energy; CP – Crude Protein; NDF – Neutral Detergent Fiber; ADF – Acid Detergent Fiber

Table 2: Experimental diets ingredients composition and nutritional values

Parameters	Control	Tifton hay	Cytric pulp	Soybean hull
<i>Ingredients composition (%)</i>				
Corn grain	83.23	61.70	40.75	72.58
Soybean oil	-	7.61	3.06	-
Soybean meal	14.00	16.93	16.72	12.98
8% NDF source	-	10.71	38.35	10.71
Salt	0.37	0.37	0.34	0.38
Limestone	1.68	0.81	0.0013	0.61
Bicálcic Phosphate	0.18	1.38	0.28	1.86
DL- Metionine (99%)	-	-	-	0.27
L-Lisine. HCl (78%)	0.33	0.29	0.30	0.40
Vitamin supplement ¹	0.10	0.10	0.10	0.10
Mineral supplement ²	0.10	0.10	0.10	0.10
<i>Nutritional values</i>				
GE (Mcal/kg)	3233	3230	3233	3100
Crude protein (%)	13.83	13.83	13.83	13.83
NDF (%)	11.47	17.43	17.00	17.41
Total lysin (%)	0.86	0.86	0.86	0.86
Calcium (%)	0.76	0.76	0.76	0.76
Total phosphorus (%)	0.31	0.32	0.35	0.31
Available phosphorus (%)	0.13	0.13	0.13	0.13

¹Quantities per kg: vit. A - 2520 UI; vit. D3 - 540 UI; vit. E - 9.9 UI; vit. K3 - 0.72 mg; tiamine - 404 mcg; riboflavine - 1.98 mg; piridoxine - 404 mcg; vit. B12 - 8.1 mcg; folic ácid - 225.2 mcg; pantotênic acid - 6.3 mg; niacine - 12.6 mg; Growth promoter - 10 mg; Se - 0.24 mg. ²Quantities per kg: Cu - 9 mg; Fe - 81 mg; I - 0.9 mg; Mn - 54 mg; Zn - 135 mg

Table 3: Initial Body Weight (IBW), Final Body Weight (FBW), Average Daily Feed Intake (ADFI), Average Daily Gain (ADG), Feed Conversion Ratio (FCR), Hot Carcass Yield (HCY), Carcass Length (CL), Back fat Thickness (BT), Loin Eye Area (LEA) and Fat-to-Meat ration (F/M) of pigs fed control, Tifton hay, Cytric pulp and Soybean hull diets

Parameters	Control	Tifton hay	Cytric pulp	Soybean hull	SED ¹
IBW (kg)	70.52	71.12	70.27	72.13	-
FBW (kg)	97.82 ^b	97.52 ^b	81.53 ^c	108.73 ^a	8.09
ADG (kg/d)	0.91 ^b	0.88 ^b	0.37 ^c	1.22 ^a	21.98
ADFI (kg/d)	2.63 ^b	2.34 ^c	1.88 ^d	2.84 ^a	8.51
FCR	2.89 ^b	2.65 ^b	5.08 ^c	2.33 ^a	37.94
HCY (kg)	81.72	80.54	80.30	80.24	3.70
CL (cm)	90.65	90.04	88.80	87.78	3.23
BT (cm)	2.13	2.30	2.39	2.42	14.92
LEA (cm ²)	35.25	35.13	34.11	34.12	9.44
F/M	0.38	0.39	0.39	0.41	15.31

^{abc} – Means followed by different superscript letter differ significantly (p<0.05); SED – Standard Error Deviation

As for digestible NDF and ADF, Soybean hulls showed levels of 21.70 and 26.39%, respectively. Table 3 presents the results of growth performance and carcass parameters of pigs fed the experimental diets. Offering different fiber sources for finishing pigs affected FBW, ADG, ADFI and FCR (p<0.05). The highest FBW value was observed in pigs fed Soybean hull and the lowest ADG value was found for pigs fed Cytric pulp diet (p<0.05). Pigs fed Control and Tifton hay showed intermediate values for these parameters, without differing from each other (p>0.05). In addition, significant (p<0.05) values of ADFI were found for Soybean hull, Control, Tifton hay and Cytric pulp. Pigs fed Control and Tifton hay diets present similar (p>0.05) FCR values, being these higher than Soybean hull and lower than Cytric pulp diet (p<0.05). Significant effects were not observed (p>0.05) for HCY, CL, BT, LEA and F/M parameters.

Discussion

Chemical analyses and feeding tests are the first items to determine feed nutritional potential. Animal species utilize feed nutrients differently and this variation may be quantified by determining their digestibility coefficients. Digestibility may be defined as the efficiency with which the animal digests and absorbs the nutrients and energy contained in a diet and digestibility determination of a specific ingredient is the first step when it comes to evaluating its potential for inclusion in animal diets (Pezzato *et al.*, 2002).

The results of chemical composition, gross energy content, DC and DN of the different fibrous sources are in agreement with those presented in by the Brazilian requirements for poultry and swine tables (Rostagno *et al.*, 2011) and also in accordance with the postulates of Gomes (2006) and Watanabe (2007), which evaluated the inclusion of "Coast Cross" hay and Citrus pulp in pig diets. Despite the fact that the digestibility of ingredients and not that of the diets was evaluated in the present

study, for comparison purposes, Lun *et al.* (1988) found similar digestibility values for DM, CP, digestible energy and metabolizable energy in diets of growing pigs with 50% replacement of corn by triticale; however, increased dietary fiber resulted in a decrease in CP apparent digestibility, absorbed and fecal nitrogen, which likely was due to the higher microbial protein synthesis in the large intestine and hence, increased bacterial nitrogen excretion (Sauer *et al.*, 1991), thus decreasing protein digestibility.

According to Gomes *et al.* (2007) the reduction of DM digestibility in diets containing increased NDF content may be attributed to the replacement of a highly digestible carbohydrate (corn starch) source by a less digestible one such as grass hay, rich in non-starch polysaccharides. These are widely known for its reduced degree of fermentability and they may also lead to faster passage rate of digesta through the gastrointestinal tract, which reduces their fermentation as well.

As observed in our study, Watanabe (2007) showed that Citrus pulp had high digestibility coefficient (72.60%), possibly due to increased soluble crude fiber, subject to greater fermentation. These authors also stated that the effects of the inclusion of fiber sources on feed digestibility varies according to the solubility of their constituents. In view of the present results of this study, we can conclude that given the fact that pigs in the finishing phase already present complete development of the digestive system, they are capable of degrading the diverse fiber components, especially in the cecum, varying according to the NDF and ADF content of the evaluated ingredient.

Concerning growth performance and carcass traits evaluation, several studies were performed evaluating the inclusion of different levels of fibrous sources the diet, however, this study did not aim to evaluate the inclusion levels, but to determine which one of our fiber sources would generate more benefits by including them in the nutritional matrices of finishing pigs, representing an addition of 8% NDF, as theorized by Gomes (2006).

The most promising results for FBW, ADG and FCR were observed in animals fed Soybean hulls. In the literature, there are very few studies with pigs fed on Soybean hulls, especially comparing to different fiber sources. And still, since it is a by-product of Soybean oil production, there is no such thing as a standardized production, making the comparison of different sources of Soybean hulls inadequate.

Shriver *et al.* (2003), included 10% of Soybean hulls in diets for growing and finishing pigs and found no effects on performance and carcass characteristics. Similarly, pigs in growing and finishing phase fed isoenergetic diets with inclusion of 0, 4, 8, 12 and 16% of Soybean hulls showed no differences in ADFI, ADG and FCR.

Evaluating different inclusion levels (0, 5, 10 and 15%) of Soybean hulls in diets for pigs, Wang *et al.* (2009) pointed out that this by-product does not affect animal performance corroborating the results reported by Kornegay (1981) and Van Oeckel *et al.* (1998). Nevertheless, DeCamp *et al.* (2001) concluded that 10% inclusion of Soybean hulls in finishing swine diets increased ADFI and improved FCR of the animals since diets are supplemented with an energy source such as Soybean oil. Still, this fact differs from results obtained in the present study because even without an energy supplementation, the animals showed better results.

Although the Soybean hulls treatment have shown a slight reduction in ME, the consumption of this ingredient may have been increased in order to balance the reduction of metabolizable energy caused by the addition of fiber sources in diet (Huo, 1993).

By analyzing the experimental diets, it can be seen that they were isonutritives, with minor differences. However, the short-chain fatty acids derived from the fiber fermentation in the large intestine, although not quantified in this study, are likely to have provide additional energy to the animals (Kass *et al.*, 1980), at levels which depend on the age and category of animal. This factor, however, was not considered in the calculation of the experimental diets.

The most remarkable results in this study, obtained when using Soybean hulls, are probably due to short-chain fatty acids such as acetic, propionic and butyric acid, generated by microbial digestion in the cecum of the pigs, which are subsequently by blood stream and participate in the Krebs cycle generating Adenosine Triphosphate (ATP), contributing to the energy metabolism of animals. The metabolizable energy value calculated for Soybean hulls treatment was 3100 kcal/kg, however, considering the facts described above, this value was probably underestimated.

To achieve the inclusion of 8% NDF in the diets, it was necessary to include about 11% of Tifton hay and

soybean hulls, while 39% of Citrus Pulp was necessary. Naturally, the high inclusion of citrus pulp resulted in reduction of animal performance, due to the decreased feed intake which is attributed to the astringent flavor of this ingredient. On the other hand the studies of Watanabe (2007) have demonstrated that the Citrus pulp has a high DM coefficient digestibility (72.6%), possibly due to its high soluble fiber content available for gut fermentation.

The decreased performance of animals fed Tifton hay and Citrus pulp may be due to changes in nutrient absorption rate, especially protein and amino acids (King and Taverner, 1975).

Concerning carcass parameters, no effects were observed in the present study, diverging from Pond (1989) which reported benefits when introducing fibrous sources in pig diet regarding carcass characteristics. However other authors like Hale and Utley (1985), evaluated the inclusion of 20% of soybean hulls in pig diet and similarly to the results obtained here, no effects were observed on carcass characteristics. Given the results obtained in this study, Soybean hull showed to be a promising ingredient to be used in diets of finishing pigs, leading to good results on animal performance and also contributing to the sustainability of pig production.

Conclusion

Given the results obtained in this study, it can be concluded that soybean hulls is an excellent ingredient to be used in finishing pig diets.

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Statement of Animal Rights

All procedures performed in involving animals were in accordance with the ethical standards of the institution at which the studies were conducted (Ethics Committee on Animal Use of the Escola Superior de Agricultura "Luiz de Queiroz" – CEUA-ESALQ/USP Proctol No. 0127.2014).

Author's Contributions

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Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and there are no ethical issues involved.

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