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Effect of processed maize stover as an alternative energy source in swine production

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ABSTRACT. In order to increase the nutritive values of maize stover, the processes of steam explosion and microbial fermentation with *Aspergillus oryzae* were used to produce processed maize stover (PMS). In the digestive experiment on swine it was shown that dietary digestible energy (DE) was decreased when PMS substitute rates for maize meal were increased from 5 to 15% ($P < 0.05$). In each of two-stage swine feeding experiment were 5 groups with 3 replications in each: group 1 – control, groups 2–4 – diets supplemented with 5, 10 or 15% PMS, respectively (as a replacement of the same amount of maize meal), group 5 – diet supplemented with 10% PMS with DE level the same as in the control group. It was indicated that average daily gain and nutrient digestibility were similar in groups with 0 and 5% PMS addition but were decreased when PMS addition increased from 5 to 15%. It can be concluded that the optimal levels of PMS in diets were below 10% for younger pigs and 15% for older ones. PMS addition could help to increase faecal enzyme activity and decrease swine diarrhoea rates. So, the insights that optimal PMS levels could relieve shortage of energy feedstuffs were provided in this study.

Introduction

Energy sources and edible carbohydrate shortages are the world-wide problems. Lignocellulose, which yearly production is about 7 billion tons with 70% belonging to crop stalks, is the largest renewable energy source (Kaur and Kuhad, 2019). Unfortunately, most of it is discarded, buried or burned in the field because lignin can maintain the cell wall permeability and support the plant cell wall, which is combined with cellulose and hemicelluloses to form crystal structure to resist enzymatic hydrolysis and microbial attack for the further application (Saha et al., 2005). If lignocellulose is transferred to low-molecular carbohydrate, it will help to solve energy crisis.

In numerous studies it was shown that physical, chemical and biological treatments are the effective methods improving the potential value of crop straw to be used as feedstuff for monogastric animals, at the same time replacing the conventional grains such as maize, wheat, rice and others (Chang et al., 2015; Aguilar et al., 2018; Kaur and Kuhad, 2019; Siddhu et al., 2019; Wang et al., 2019). In our previous research we have shown that *Aspergillus oryzae* can produce numerous kinds of enzymes such as protease, amylase, cellulase to help degrade maize stover (Chang et al., 2015); therefore, it is appropriate for feed fermentation.

The optimal dietary fibre content is beneficial for the development of pig intestine and the reduction

of diarrhoea rate, however high dietary fibre level can reduce the nutrient digestibility (Chen et al., 2015). It was reported that the optimal dietary crude fibre level for pig growth is about 6% (Le Gall et al., 2009; Molist et al., 2014). The increased abundance of cellulose-degrading bacteria in the colon after addition of 10% oat bran to the diet of weaned piglets was observed by He et al. (2018). Luo et al. (2018) reported that the addition of pea fibre to pig diet promoted productions of butyrate and volatile fatty acids in the intestinal tract. So, different fibre sources and levels may have the different effects on pig responses (Slavin et al., 2009).

Maize stover includes 70–85% lignocellulose and some protein, fat, calcium, phosphorus and minerals, which have a potential value in animal production (Graminha et al., 2008; Mourtzinis et al., 2016). The physical, chemical and biological treatments will help to destroy maize straw structure for further lignocellulose degradation and as a result to make processed maize stover (PMS) for broiler growth (Chang et al., 2015; Wang et al., 2019).

In order to solve the problems of energy sources and edible carbohydrate shortages in pig production, this study was focused on improving by the physical and biological methods the nutritional value of maize stover as a possible substitute of maize meal.

Material and methods

The preparation of the maize stover

The maize stover was obtained from the experimental farm in Henan Agricultural University, Zhengzhou (China). The air-dried maize stover was hammer-milled and screened to obtain pieces of 210 mm in size. The steam explosion of maize stover was carried out by a steam explosion equipment (QBS-200, Zhengdao Machine Factory, Hebi, China). About 50 kg mashed maize stover was put into a steam chamber. The steam was adjusted to 2.5 MPa pressure and kept for 200 s, and then suddenly released at the end of treatment to give explosion effect. The exploded samples were collected and dried naturally to 90.1% dry matter content before microbial fermentation.

Solid-state fermentation of maize stover

The fermented materials were composed of 90% exploded maize stover, 4% maize meal, 3% wheat bran, 3% soybean meal, in which 60% of minerals was added and mixed (v/w). The pH value of the fermented materials was adjusted to 7.0 by $Ca(OH)_2$. The mineral mixture contained (g/l): $(NH_4)_2SO_4$ 1.4, KH_2PO_4 2.0, $MgSO_4$ 0.3, $CaCl_2$ 0.3, NaCl 0.5, $FeSO_4$ 0.0050, $MnSO_4$ 0.0016, $ZnCl_2$ 0.0017, $CoCl_2$ 0.0020. All the above materials were autoclaved at 121 °C for 15 min, and then 4% (v/w) *Aspergillus oryzae* suspension (1×10^6 spores/ml) was added and mixed. *Aspergillus oryzae* suspension was prepared as the following: *Aspergillus oryzae* was incubated in the flasks containing the above fermented materials in which the exploded maize stover was replaced by the wheat bran, the suspension was obtained by adding normal saline at 10:1 (v/w) after 6 days of incubation at 30 °C. The microbial fermentation of maize stover was carried out at 30 °C for 6 days. The fermented sample was dried at 65 °C up to about 90% dry matter, and then ground to the size of 420 μm.

Nutrient determinations

Cellulose and hemicelluloses contents in the samples were determined in line with the previous protocol (Van Soest et al., 1991). The process was as following: 0.5 g sample was added into a nylon bag and sealed. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) measurements were conducted by boiling in neutral detergent solution and acid detergent solution for 60 min, respectively. Both of them were washed with boiling water until no detergent was detected, and then dried at 105 °C. After acid detergent extraction, the nylon bag was dipped in 72% (v/v) sulphuric acid for 3 h, washed until no sulphuric acid was detected, and dried at 105 °C. The residues in nylon bag were ashed at 600 °C to obtain the residual ash. The hemicelluloses and cellulose contents were calculated as the following:

$$\text{hemicellulose (\%)} = \text{NDF (\%)} - \text{ADF (\%)},$$

$$\text{cellulose (\%)} = \text{ADF (\%)} - \text{residues with 72\% sulphuric acid treatment (\%)}.$$

About 5.0 g native and differently treated maize straw were soaked in 50 ml distilled water for 24 h at 40 °C and then filtered. The filtrate was used to measure total reducing sugar content with dinitrosalicylic acid (DNS) method (Miller, 1959). Dry matter and crude protein contents in PMS, diets and faeces were determined according to international procedures of AOAC (1990). Calcium (Ca) and phosphorus (P) contents were determined with potassium permanganate ($KMnO_4$) and ammonium molybdate ($(NH_4)_6Mo_7O_{24}$) protocols (Jurgens, 1997). The gross energy in the diets and faeces was determined with an oxygen bomb calorimeter (IKA-C2000, IKA Instrument Company, Staufen, Germany).

Experimental design and animal feeding management

Prior to the two-stage feeding experiment, 7-days adaptive phase was conducted. In the earlier feeding stage, 120 ninety-day-old barrows (Landrace × Yorkshire) were assigned to 5 groups with 3 replications in each group, and 8 barrows for each replication in one pen. The experimental period was 30 days. In the later feeding stage, 105 barrows at the age of 120 days were assigned to 5 groups with 3 replications in each group, and 7 barrows for each replication in one pen. The experimental period lasted also 30 days. The feeding experiment design is presented in Table 1.

Table 1. Experimental design

Group	Processed maize stover (PMS) contents in the basal diets
1	The basal diet (control group)
2	Maize meal in basal diet replaced by 5% PMS
3	Maize meal in basal diet replaced by 10% PMS
4	Maize meal in basal diet replaced by 15% PMS
5	Maize meal in basal diet replaced by 10% PMS (dietary digestible energy content was adjusted to the same levels as control group with soybean oil)

The dry mash diets and water were given *ad libitum*. The compositions and nutrient levels of the experimental diets are shown in Table 2.

All animals were managed according to the guidelines for care and use of experimental animals approved by The Ethics Committee of Henan Agricultural University (SKLAB-B-2010-003-01).

Productive performance

During both feeding experiments, the initial and final body weights of pigs in each replication were measured, and then average daily gain (ADG) was calculated. Feed intake in each replication was measured daily, and average daily feed intake (ADFI) was calculated. Feed conversion rate (FCR) was calculated based on the ratio of ADFI/ADG. The pigs with watery faeces around anus were considered as having diarrhoea, the diarrhoea rate was calculated as following: number of pigs with diarrhoea / total pigs.

Nutrient digestibility determination

There were two digestion trials. The first one was to measure digestible energy (DE) contents in diets containing different levels of PMS for preparing the diet in group 5. In the first digestion trial for DE determination, twenty castrated fattening

Table 2. Feed compositions and nutrient levels of the diets, %

Indices	90–120 days					120–150 days				
	Groups[1]					Groups[1]				
	1	2	3	4	5	1	2	3	4	5
Feed composition										
maize meal	66.00	61.47	57.02	52.60	54.00	72.35	67.81	63.47	58.80	60.17
soybean meal	24.50	24.29	24.00	23.65	24.39	20.70	20.50	20.10	20.00	20.70
processed maize stover	0.00	5.00	10.00	15.00	10.00	0.00	5.00	10.00	15.00	10.00
wheat bran	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
calcium carbonate	0.83	0.57	0.30	0.05	0.30	0.83	0.57	0.30	0.05	0.30
calcium phosphate	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
lysine	0.10	0.10	0.11	0.13	0.11	0.10	0.10	0.11	0.13	0.11
calcium salt	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
soybean oil	1.05	1.05	1.05	1.05	3.68	0.50	0.50	0.50	0.50	3.20
premix[2]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Nutrient levels										
DE, MJ/kg	13.60	13.26	13.02	12.72	13.61	13.60	13.31	13.01	12.72	13.60
crude protein	17.51	17.49	17.48	17.47	17.50	16.01	15.99	15.98	15.99	16.02
NDF	16.23	18.05	20.13	21.98	20.07	17.88	19.81	21.72	23.64	21.73
ADF	5.71	7.53	9.56	11.32	9.61	6.67	8.57	10.51	12.43	10.49
calcium	0.66	0.67	0.68	0.66	0.67	0.59	0.61	0.59	0.58	0.60
phosphorus	0.53	0.54	0.54	0.55	0.54	0.49	0.51	0.49	0.51	0.51
lysine	0.95	0.95	0.95	0.95	0.95	0.85	0.85	0.85	0.85	0.85

[1] groups according to Table 1; [2] premix composition (per kg of diet), mg: Cu (copper sulphate) 2597, Fe (ferrous sulphate) 2945, Zn (zinc oxide) 2665, Mn (manganese sulphate) 1190, I (calcium iodate) 197, Se (sodium selenite) 197, nicotinic acid 61.8, pantothenic acid 32.96, biotin 0.21, choline 125; IU: vit. A 29400, vit. D_3 2200, vit. E 1650, vit. K_3 1.03, vit. B_1 0.515, vit. B_2 14.7, vit. B_{12} 61.8; DE – digestible energy, NDF – neutral detergent fibre, ADF – acid detergent fibre; nutrient contents except for lysine were analysed

crossbred pigs (Landrace × Yorkshire) with body weight of 70 kg were selected and divided into four groups randomly, 5 pigs in each group. The pigs were fed with 4 different diets referring to the diets in groups 1–4 in the later feeding period. The digestion trial was carried out for 7 days including 4-day preliminary preparation and 3-day trial. During the trial period, fresh excreta were collected daily from each pig. About 100 g samples were taken after mixing, and then 10% sulphuric acid was sprayed immediately and kept at −20 °C. At last, the excreta samples from 3-day collection were mixed and dried at 65 °C, crushed and passed through a 40 mesh sieve for further use. Meanwhile, the diet samples were also taken for nutrient analysis. The total energy and acid insoluble ash (AIA) contents in the diets and faeces were measured. The energy digestibility of the diet was determined by 4 N HCl insoluble ash. Energy digestibility (%) = 100 − (100 × acid insoluble ash content in diet / acid insoluble ash content in faeces × total energy in faeces / total energy in diet). The dietary digestible energy was calculated based on energy digestibility.

The second digestion trial for nutrient digestibility determination was conducted at the end of later feeding period. Nutrient digestibility was measured with the same protocol as above.

Determinations of faecal enzymatic activity

Fresh excreta were collected at the later feeding period, and frozen at −20 °C for further analysis. About 0.5 g faecal sample was put into a container with 4.5 ml sterilized saline water, stirred for 10 min, and the supernatant was used for enzymatic activity analysis. The filter paper activity (FPA) of cellulase was measured as the following: one unit of cellulase was defined as the amount of cellulase that released 1 μmol of glucose per min at pH 4.8 and 50 °C using filter paper as a substrate. Carboxymethyl-cellulose (CMC) activity of cellulase was measured with 1% CMC as the substrate (Ghose, 1987). The amylase activity was determined by using soluble starch as the substrate (Leroy et al., 2008), one unit of amylase activity was defined as the amount of enzyme releasing 1 μmol glucose per min. The protease activity was determined by the previous method (Sandhya et al., 2005), one unit of protease was defined as the amount of enzyme that liberated l μmol tyrosine per min.

Statistical analysis

Experimental data were expressed as means and standard errors (mean ± SE), analysed as a single factor design by the analysis of variance (ANOVA) using IBM SPSS-Statistics Program 20.0 (IBM, New York, NY, USA, 2012). The means were evaluated with Tukey's multiple range test, and differences were considered statistically significance at $P < 0.05$.

Results

Nutrient compositions of natural maize straw and PMS

In the Table 3 it is shown that NDF, ADF, cellulose and hemicellulose contents in PMS were significantly decreased ($P < 0.05$), while the total reducing sugar content was significantly increased ($P < 0.05$) in comparison with the natural maize straw.

Table 3. Nutrient compositions of natural maize straw and processed maize stover, n = 5

Indices, %	Maize stover	Processed maize stover
NDF	79.3 ± 1.31[a]	38.7 ± 0.42[b]
ADF	59.2 ± 2.00[a]	38.3 ± 0.76[b]
Cellulose	41.3 ± 2.31[a]	17.5 ± 0.72[b]
Hemicellulose	20.0 ± 1.18[a]	0.0 ± 0.00[b]
Reducing sugar	4.8 ± 0.12[b]	18.1 ± 1.06[a]

[ab] – means with different superscripts in the same row are significantly different at $P < 0.05$; NDF – neutral detergent fibre, ADF – acid detergent fibre

Digestible energy determination of PMS

In the Table 4 we have shown that the dietary digestible energy in diets was significantly decreased with increasing PMS substitute rates for maize meal from 0 to 15% ($P < 0.05$).

Table 4. Dietary digestible energy with different levels of processed maize stover (PMS) additions, n = 5

Groups[1]	PMS contents,%	Dietary digestible energy, MJ/kg
1	0	13.72 ± 0.18[a]
2	5	13.30 ± 0.20[b]
3	10	13.01 ± 0.21[b]
4	15	12.59 ± 0.14[c]

[1] groups according to Table 1; [a,b,c] – mean with different superscripts in the same column are significantly different at $P < 0.05$

Effect of PMS on production performance of pigs

Swine production performance is presented in Table 5. In the first feeding period ADG was decreased significantly when 15% of PMS was added ($P < 0.05$) in comparison with other groups. There were no significant differences in ADG among the other groups ($P > 0.05$) except for the groups

Table 5. Effect of dietary processed maize stover supplementation on swine production performance during both feeding stages, n = 3

Indices	Groups[1]				
	1	2	3	4	5
90–120 days					
initial weight, kg	33.8 ± 1.3	33.5 ± 1.0	34.1 ± 1.8	33.2 ± 2.0	33.9 ± 1.2
final weight, kg	49.9 ± 0.5^{a}	49.1 ± 5.0^{a}	48.2 ± 1.3^{ab}	45.3 ± 2.0^{b}	50.2 ± 2.0^{a}
ADG, g/d	538 ± 16^{a}	520 ± 46^{a}	478 ± 69^{ab}	420 ± 35^{b}	545 ± 66^{a}
ADFI, g/d	1277 ± 23	1424 ± 65	1303 ± 85	1269 ± 82	1297 ± 103
FCR	2.38 ± 0.8^{b}	2.75 ± 0.14^{b}	2.75 ± 0.30^{b}	3.04 ± 0.22^{a}	2.39 ± 0.09^{b}
diarrhoea rate, %	8	4	5	4	5
120–150 days					
initial weight, kg	51.3 ± 1.4	49.6 ± 1.3	49.9 ± 1.1	51.9 ± 1.8	51.3 ± 1.4
final weight, kg	68.1 ± 9.1	69.0 ± 1.3	69.2 ± 6.2	7.5 ± 8.2	74.8 ± 5.5
ADG, g/d	635 ± 53^{ab}	646 ± 36^{ab}	616 ± 87^{ab}	582 ± 58^{b}	774 ± 73^{a}
ADFI, g/d	1992 ± 360	2025 ± 86	1982 ± 324	2140 ± 166	2261 ± 62
FCR	3.15 ± 0.10^{bc}	3.14 ± 0.04^{bc}	3.24 ± 0.18^{b}	3.68 ± 0.08^{a}	2.94 ± 0.14^{c}
diarrhoea rate, %	4	0	2	0	1

[1] groups according to Table 1; ^{a,b,c} – means with the different superscripts in the same row are significantly different at $P < 0.05$; while means with the same or without superscripts in the same row are insignificantly different at $P > 0.05$; ADG – average daily gain, ADFI – average daily feed intake, FCR – feed conversion ratio (FCR = ADFI / ADG), diarrhoea rate (%) = number of pigs with diarrhoea / total pigs × 100

4 and 5. PMS had no significant effect on ADFI among 5 groups ($P > 0.05$). FCR in the group with 15% PMS addition was higher than that in other groups ($P < 0.05$). The diarrhoea rates in groups 2–5 were decreased by 43–51% in comparison with the control group.

In the second feeding period, ADG in group 5 was higher than that in group 4 ($P < 0.05$). There were no significant differences of ADG among the other groups ($P > 0.05$). PMS did not significantly affect ADFI among 5 groups ($P > 0.05$). The lowest FCR was observed in group 5, then 2 and 1; the highest FCR was observed in pigs from group 4. The diarrhoea rates in groups 2–5 were decreased by 38–96% in comparison with the control group. The adjusted DE levels in PMS diet during both feeding stages would help to improve swine production performance and FCR.

Effect of different PMS addition levels in swine diets on nutrient digestibility

Dry matter, energy, crude protein, NDF, ADF, calcium and phosphorus digestibilities significantly decreased as PMS addition increased from 5 to 15% ($P < 0.05$) (Table 6). Except for NDF digestibility, almost all the nutrient digestibilities in the control group were significantly higher than those in other groups ($P < 0.05$).

Effect of dietary PMS supplementation on faecal enzyme activity in pigs

Faecal CMC activity in groups supplemented with 10–15% PMS was higher than in group supplemented with 5% PMS and control group ($P < 0.05$) (Table 7). Filter paper activities (FPA) in the four PMS groups were significantly higher than that in the control group ($P < 0.05$).

Table 6. Effect of processed maize stover on nutrient digestibility in pigs, n = 5

Indices, %	Groups[1]				
	1	2	3	4	5
Dry matter	87.1 ± 1.0^{a}	82.6 ± 1.4^{b}	78.8 ± 1.3^{c}	74.7 ± 1.8^{d}	76.4 ± 0.2^{d}
Energy	87.5 ± 1.1^{a}	81.2 ± 2.5^{b}	77.9 ± 1.5^{bc}	75.0 ± 2.9^{c}	76.8 ± 0.3
Crude protein	82.6 ± 1.6^{a}	81.0 ± 0.6^{ab}	74.7 ± 0.4^{c}	72.4 ± 0.6^{d}	79.2 ± 1.9^{ab}
NDF	84.0 ± 1.7^{b}	86.0 ± 0.9^{a}	82.8 ± 1.0^{bc}	80.3 ± 1.0^{c}	80.7 ± 0.7^{c}
ADF	61.7 ± 0.9^{a}	62.3 ± 1.0^{a}	48.4 ± 1.4^{b}	36.8 ± 1.0^{d}	41.7 ± 1.0^{c}
Calcium	70.0 ± 2.9^{a}	53.9 ± 3.1^{b}	56.8 ± 4.3^{b}	53.0 ± 1.6^{b}	51.8 ± 2.7^{b}
Phosphorus	57.6 ± 0.0^{a}	40.6 ± 3.4^{b}	44.3 ± 0.6^{b}	41.0 ± 0.1^{b}	43.5 ± 0.8^{b}

[1] groups according to Table 1; ^{a,b,c,d} – means with different superscripts in the same row are significantly different at $P < 0.05$; NDF – neutral detergent fibre, ADF – acid detergent fibre

Table 7. Effect of dietary processed maize stover supplementation on faecal enzyme activity in pigs, n = 5, U/g faeces

Groups[1]	CMC	FPA	Amylase	Protease
1	18.4 ± 0.67^{b}	0.22 ± 0.01^{c}	142.0 ± 21.57^{b}	21.6 ± 0.53^{bc}
2	16.8 ± 0.23^{b}	5.88 ± 0.34^{b}	273.5 ± 10.78^{a}	20.0 ± 1.41^{c}
3	21.1 ± 1.12^{a}	8.03 ± 1.12^{a}	174.4 ± 5.39^{b}	16.8 ± 0.13^{d}
4	21.4 ± 0.45^{a}	4.37 ± 0.67^{b}	244.0 ± 4.04^{a}	56.3 ± 1.13^{a}
5	22.8 ± 1.34^{a}	5.85 ± 0.06^{b}	139.1 ± 33.69^{b}	23.7 ± 0.61^{b}

[1] groups according to Table 1; ^{a,b,c} – means with different superscripts in the same column are significantly different at $P < 0.05$; FPA – filter paper activity of cellulase, CMC – carboxymethyl-cellulose activity of cellulase

The faecal amylase activity in groups supplemented with 5 and 15% PMS was significantly higher than that in other groups ($P < 0.05$). The faecal protease activity changing order was: group 4 > group 5 > group 1 and group 2 > group 3 ($P < 0.05$).

Discussion

It was shown that physical pretreatment combined with microbial fermentation could decrease lignocellulose contents in maize straw and as a result could be a possible method to partly replace maize meal with such processed maize straw in swine diet. In the previous report it was indicated that the cellulose and hemicellulose contents in maize straw significantly decreased when the exploded maize straw was fermented for 7 days by *Trichoderma koningii* (Du et al., 2019) and this finding was also observed in this research. In general, lignocellulose structure is destroyed by steam explosion, which is conducive to microbial attack for making low-molecular carbohydrates.

Taking into account the results in both feeding trials, it could be concluded that the optimal levels of PMS in diets were below 10% for the younger pigs and 15% for the older ones, indicating that PMS additions should agree with different ages of pigs. However, in line with increasing PMS addition there is observed a decreasing tendency in pig growth, especially visible in younger pigs. High lignocellulose and low DE contents in PMS and the immature digestive tract of young pigs can be the reason of such situation. Dietary fibre, as shown in other study, would inhibit pig growth when its content in growing pig diets was over 7.5% (Thacker and Haq, 2008); our present results correspond with this observation. The adjusted DE levels in PMS diets exerted no significant effects on swine production performance, indicating that DE level in PMS was enough to maintain pig growth (control group). Although pigs can adapt to relatively high-fibre-level diet, dietary fibre is considered as an important factor affecting palatability and feed intake in pigs (Solà-Oriol et al., 2009). At the same time, high fibre content increases chyme wriggling speed to lower nutrient digestibility (Ndou et al., 2013). Due to intestinal filling, high fibre levels in the diet can reduce the amount of feed voluntarily consumed, thereby affecting pig energy intake (Da Silva et al., 2010). In another report it was shown that increasing level of dietary fibre can lead to an increase in feed intake, which may be related to the fact that fibre promotes the development of gastrointestinal tract in weaned piglets (Molist et al., 2014). Veum et al. (2009) in sow's experiment showed that gestation-lactation sow reproduction was increased when 13.35% ground wheat straw was added to the diets. However, it was observed that 2.5 or 5% of straw, sugar beet pulp, oat hulls or wheat middlings had no significant effect on piglet performance, but increased the incidence of post-weaning diarrhoea and deceased feed efficiency and nutrient digestibility (Berrocoso et al., 2015). The reasons of the different pig responses to straw additions may be due to the different straw treated methods, pig types, feeding conditions, straw sources and addition levels.

Nutrient digestibility is necessary to accurately formulate animal diet; therefore, DE evaluation of PMS is very important before swine feeding experiment. In the previous report it was indicated that digestive energy of maize germ meal was 13.93 MJ/kg in pigs (Shi et al., 2018), corresponding with DE level in the control group in this study. With the addition of 15–55% beet dregs containing 22% soluble dietary fibre and 47.1% insoluble dietary fibre to the basal diet. DE levels were decreased from 14.7 to 13.1 MJ/kg (Zhang et al., 2013). There was a negative correlation between NDF level and digestible energy in growing pig diets, in which digestible energy was decreased by 0.81% when dietary NDF level was increased by 1% (Noblet et al., 1994). The reason why PMS addition decreases nutrient digestibility may be due to the crude fibre in diets which accelerates the nutrients passing through the digestive tract.

As it was previously reported, high dietary fibre level would prevent the contact of enzyme with feed to reduce the digestion of nutrients (Ehle et al., 1982; Le Gall et al., 2009). Also, dietary fibre was able to affect digestion and absorption of minerals such as Ca, P, Cu, Fe (Noblet and Le Goff, 2001; De Leeuw et al., 2008). Wilfart et al. (2007) by adding 20–40% wheat bran to the wheat-barley-soybean meal diet, found that increasing dietary fibre level significantly reduced the apparent digestibility of dry matter, organic matter, crude protein and energy. In general, PMS addition in this study caused negative effect on nutrient digestibility, especially when added in high amounts.

Low diarrhoea rates in pigs fed diets supplemented with PMS may be due to cellulose nutrient function as well as the enzymes produced during microbial fermentation. It was reported that increasing dietary fibre content could reduce duration and severity of diarrhoea after piglets weaning (Yu et al., 2016; Mpendulo et al., 2018). Longland (1993) also reported that piglets had almost no obvious diarrhoea by adding wood cellulose (Solka-floc; S; Brown & Co., Berlin, NH, USA) to the pre-weaning piglet diet, and this fact was confirmed in our study. However, Berrocoso et al. (2015) reported that fibre addition increased piglet diarrhoea and suggested that it may be due to the immature digestive tract of piglets or the different fibre sources.

Porcine endogenous digestive enzymes are maximized in the pig jejunum (Lackeyram et al., 2010). Molist et al. (2014) reported that adding fibre in animal diet increased the counts of fibrolytic bacteria and short-chain fatty acid synthesis in the intestine. High activities of CMC and FPA enzyme in this study may be related to the enzymes in PMS produced during microbial fermentation or the high counts of cellulose-degrading bacteria in swine gut. However, high CMC and FPA enzyme activities caused by PMS additions had no effect on improving ADF and NDF digestibilities. This may be due to the not sufficient enzyme activity to hydrolyse the increased amount of fibre.

Conclusions

In order to increase the application potential of maize stover in pig diets, combination of steam explosion and *Aspergillus oryzae* fermentation was used to reduce the contents of cellulose and hemicelluloses. It was shown that adding around 10% processed maize stover (PMS) to pig diets in order to replace the same amount of maize meal was practicable for pig production performance. The valuable information on solving partly grain shortage in pig diets with PMS was presented.

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