Animal Nutrition 4 (2018) 228–233

Contents lists available at ScienceDirect

Animal Nutrition

journal homepage: http://www.keaipublishing.com/en/journals/aninu/

Original Research Article

Digestible energy and metabolizable energy contents of konjac flour residues and ramie in growing pigs

Enkai Li, Jinbiao Zhao, Ling Liu, Shuai Zhang*

State Key Laboratory of Animal Nutrition, Ministry of Agriculture Feed Industry Centre, China Agricultural University, Beijing 100193, China

ARTICLE INFO

Article history:
Received 1 July 2017
Received in revised form
13 December 2017
Accepted 4 January 2018
Available online 31 January 2018

Keywords:
Apparent total tract digestibility
Digestible energy
Konjac flour residues
Metabolizable energy
Ramie

ABSTRACT

The objectives of this study were to determine: 1) the effects of konjac flour residues and ramie on digestible energy (DE), metabolizable energy (ME) and apparent total tract digestibility (ATTD) of nutrients in diets fed to growing pigs, 2) the DE and ME contents of konjac flour residues and ramie. Thirty barrows were allotted to 1 of 5 treatments with 6 replicates per treatment. The 5 diets include a corn-soybean meal basal diet (CTL), konjac flour residues diets containing 15% konjac flour residues (LK) or 30% konjac flour residues (HK), and ramie diets containing 15% ramie (LR) or 30% ramie (HR). The experiment lasted 19 days, including 7 days for cage adaptation, 7 days for diet adaptation, and 5 days for total feces and urine collection. The energy values and ATTD of nutrients in each diet were determined, and DE and ME contents of konjac flour residues and ramie were calculated. The results showed that consumption of konjac flour residues significantly increased ($P < 0.01$) the fecal moisture content compared with the ramie treatment. The LK, HK and HR diets had lower ($P < 0.01$) DE values compared with the CTL diet. The HR diet had greater ($P < 0.01$) DE value compared with the HK diet. The LK and LR diets showed greater ($P < 0.01$) ATTD of DM, OM, GE and CP compared with the HK and HR diets. The HK diet had the lowest ($P < 0.01$) ATTD of ether extract (EE) among the 5 diets. No differences were observed for the ATTD of NDF and ADF among the 5 diets. Moreover, the DE and ME values of konjac flour residues under 2 inclusion levels (15% and 30%) were 11.66, 11.87 MJ/kg and 10.41, 10.03 MJ/kg, respectively. The corresponding values for ramie were 13.27, 13.16 MJ/kg and 13.07, 12.82 MJ/kg, respectively. In conclusion, the differences in fecal moisture content and the ATTD of EE among the 5 diets were mainly due to the different chemical compositions of konjac flour residues and ramie. Compared with konjac flour residues, ramie has greater DE and ME values under the same inclusion level.

1. Introduction

Increasing the inclusion proportion of fibre ingredients in swine diets can decrease the cost of feed for swine production and help to alleviate the supply and demand tension in grain market in the world (OECD-FAO, 2015). Also, fibre is required in swine diets to support normal physiological functions in digestive tract (Wenk, 2001; Yin et al., 2004). Nevertheless, dietary excess plant fibre impairs enzymatic digestion in the upper gastrointestinal tract (GIT) and increases microbial activity and digestion in the lower GIT, resulting in decreased digestibility of dietary components and dietary energy values (Noblet and Le Goff, 2001; Yin et al., 1993, Yin, 1994). However, the effect of fibre concentration on gut environment and nutrient digestibility differs with fibre properties (soluble vs. insoluble) (Högberg and Lindberg, 2006). Dietary insoluble fibre (IDF) can lead to higher flow rate of digesta, whereas dietary soluble fibre (SDF) may delay gastric emptying (Johansen et al., 1996; Guerin et al., 2001); both are important factors to influence nutrient digestion and absorption (Boudry et al., 2004).

Konjac flour has been consumed in forms of rubbery jelly, noodles, and other food products by humans for centuries, especially in Asia. Much of the recent interest in utilization of konjac

---

* Corresponding author.
E-mail address: zhangshuai16@cau.edu.cn (S. Zhang).

Peer review under responsibility of Chinese Association of Animal Science and Veterinary Medicine.

Production and Hosting by Elsevier on behalf of KeAi

https://doi.org/10.1016/j.aninu.2018.01.001

flour stems from its potential to use as SDF (Owusu-Asiedu et al., 2006). Ramie is also a traditionally grown crop, which has been mainly used as IDF, but proved to be palatable to domestic livestock. The nutritive value of ramie is reported to be similar to that of Lucerne (Kipriotis et al., 2015). However, to our knowledge, no literature has reported the energy values of konjac flour residues and ramie by now. Therefore, the objectives of this study were to: 1) evaluate the effects of konjac flour residues and ramie on digestible energy (DE), metabolizable energy (ME) and apparent total tract digestibility (ATTD) of nutrients in diets fed to growing pigs, 2) determine the DE and ME contents of konjac flour residues and ramie.

2. Materials and methods

The animal trial in this experiment was conducted in the Metabolism Laboratory of the Ministry of Agriculture Feed Industry Centre, China Agricultural University (Beijing, China). The Institutional Animal Care and Use Committee at China Agricultural University (Beijing, China) reviewed and approved the protocol of this experiment.

2.1. Sample preparation

Konjac flour residues (obtained during the production of konjac starch) used in this research were provided by New Hope Liuhe Group (Sichuan province, China). Ramie (feed-grade) used in this research was provided by Hunan Albert Animals Nutrition Group (Hunan province, China). The chemical compositions of konjac flour residues and ramie are shown in Table 1.

2.2. Animals, housing and experimental design

Thirty barrows (Duroc × Landrace × Yorkshire; initial average BW of 42.23 ± 2.1 kg) were individually housed in stainless-steel metabolism crates (1.4 m × 0.7 m × 0.6 m) at the Fengning Animal Experimental Base of China Agricultural University (Hebei, China). Each crate was equipped with a feeder, a nipple drinker, a screened floor, 2 fecal collection trays, and a urine collection bucket. Pigs had free access to water and feed. The metabolism crates were located in an environmentally controlled room with a temperature of 22 ± 1 °C.

2.3. Diets, feeding and measurements

Pigs were allotted to 1 of 5 diets according to a completely randomized design ($n = 6$). The 5 diets include a corn-soybean meal basal diet (CTL), 2 konjac flour residues diets containing 15% konjac flour residues (LK) or 30% konjac flour residues (HK), and 2 ramie diets containing 15% ramie (LR) or 30% ramie (HR). All nutrients in diets including energy, crude protein, amino acids, vitamins and minerals were designed to meet or exceed the nutrient requirements of growing pigs (NRC, 2012). Ingredients and analyzed chemical compositions of the experimental diets are listed in Table 2.

The experiment lasted 19 days, including 7 days for cage adaptation, 7 days for diet adaptation, and 5 days for total feces and urine collection. During the adaptation period, the daily amount of feed was gradually increased until it was equivalent to 4% of the BW determined at the beginning of the experiment (Adeola, 2001). The daily intake was divided equally into 2 meals provided at 08:30 and 15:30.

Pigs were weighed individually at the beginning of the adaptation period and at the end of the collection period. The amount of feed added to the feeders was recorded each feeding time. Orts were removed and weighed after each meal and daily feed consumption was calculated. Water was available *ad libitum* for each pig.

2.4. Sample collection

The feces and urine collection and sample preparation were conducted following the methods described by Li et al. (2015).

Table 1
Analyzed nutrient components of the ingredients (%, as-fed basis).

Item	Konjac flour residues	Ramie
Dry matter	89.68	92.37
Crude protein	18.56	17.21
Gross energy, MJ/kg	15.25	18.86
Ether extract	1.00	6.96
Ash	8.12	3.96
Soluble dietary fibre	13.29	3.37
Insoluble dietary fibre	14.47	57.52
Total dietary fibre	27.76	60.89
Calcium	1.28	0.34
Phosphorus	0.32	0.60
Amino acids		
Alanine	0.77	0.65
Arginine	1.40	1.62
Aspartic acid	1.83	1.10
Cysteine	0.31	0.16
Glutamic acid	2.09	2.38
Glycine	0.74	0.65
Histidine	0.36	0.22
Isoleucine	0.50	0.44
Leucine	0.92	0.91
Lysine	0.64	0.38
Methionine	0.27	0.31
Pheylalanine	0.80	0.59
Proline	0.61	0.54
Serine	0.89	0.55
Threonine	0.64	0.43
Tryptophan	0.19	0.33
Tyrosine	0.48	0.31
Valine	0.95	0.72

Table 2
Ingredient compositions and analyzed nutrient components of the experimental diets (%, as-fed basis).

Item	Treatments[1]				
	CTL	LK	HK	LR	HR
Ingredients					
Corn	72.80	61.63	50.47	61.63	50.47
Soybean meal	25.00	21.17	17.33	21.17	17.33
Konjac flour residues		15.00	30.00		
Ramie				15.00	30.00
Dicalcium phosphate	0.60	0.60	0.60	0.60	0.60
Salt	0.35	0.35	0.35	0.35	0.35
Limestone	0.75	0.75	0.75	0.75	0.75
Premix[2]	0.50	0.50	0.50	0.50	0.50
Nutrient compositions					
Dry matter	87.55	87.71	88.09	88.44	89.21
Gross energy, MJ/kg	16.60	16.40	16.21	17.01	17.20
Ether extract	2.42	2.23	2.21	3.66	3.88
Crude protein	18.02	17.29	18.00	17.47	16.83
Soluble dietary fibre	4.54	8.55	10.01	4.10	2.00
Insoluble dietary fibre	9.43	10.15	11.01	16.47	23.51
Total dietary fibre	13.97	18.70	21.02	20.57	25.51

[1] CTL: corn-soybean basal diet; LK: diets containing 15% of konjac flour residues; HK: diets containing 30% of konjac flour residues; LR: diets containing 15% of ramie; HR: diets containing 30% of ramie.

[2] Premix provided the following per kg of complete diets for growing pigs: vitamin A, 5,512 IU; vitamin D_3, 2,200 IU; vitamin E, 30 IU; vitamin K_3, 2.2 mg; vitamin B_{12}, 27.6 μg; riboflavin, 4 mg; pantothenic acid, 14 mg; niacin, 30 mg; choline chloride, 400 mg; folacin, 0.7 mg; thiamine 1.5 mg; pyridoxine 3 mg; biotin, 44 μg; Mn, 40 mg (MnO); Fe, 75 mg ($FeSO_4 \cdot H_2O$); Zn, 75 mg (ZnO); Cu, 100 mg ($CuSO_4 \cdot 5H_2O$); I, 0.3 mg (KI); Se, 0.3 mg (Na_2SeO_3).

Specifically, feces were collected into plastic bags (one bag per pig) upon appearance in the metabolism crates and immediately stored at −20 °C during the feces collection period. The 5-day fecal production from each pig were pooled and weighed and a 300-g subsample was taken and dried in oven at 65 °C for 72 h, and then stored at −20 °C for further chemical analysis after grinding. During urine collection, 50 mL of 6 mol/L HCl was added and the volume of collected urine was measured each day. A sub-sample of 100 mL was filtered and transferred into a screw-capped bottle per litter and then stored at −20 °C for further chemical analysis. Samples of diets and ingredient were collected and stored at −20 °C for further analysis.

2.5. *Chemical analyses*

Konjac flour residues and ramie were analyzed for calcium (Ca) and phosphorus (P) following the method 985.01. The total dietary fibre (TDF) and IDF were measured according to the method 985.29, and the concentration of dietary SDF was calculated as the difference between TDF and IDF. The amino acids in ingredients were analyzed according to Huang et al. (2014). In brief, 15 amino acids were analyzed with 6 mol/L HCl hydrolysis at 110 °C for 24 h using an Amino Acid Analyzer (Hitachi L-8900, Tokyo, Japan). Tryptophan was determined after LiOH hydrolysis for 22 h at 110 °C using HPLC (Agilent 1200 Series, Santa Clara, CA, USA). Methionine and cysteine were measured after cold performic acid oxidation overnight and 7.5 mol/L HCl hydrolysis at 110 °C for 24 h as the forms of methionine sulfone and cysteic acid using an Amino Acid Analyzer (Hitachi L-8800, Tokyo, Japan).

The dry matter (method 934.01), ether extract (method 920.39), ash (method 942.05) and crude protein (method 990.03) of the diets and feces were analyzed according to the procedures of the AOAC International (2007). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined using fibre bags (model F57; Ankom Technology, Macedon, NY) and the fibre analyzer (ANKOM200 Fibre Analyzer; Ankom Technology) based on a modified procedure as described by Van Soest et al. (1991). The concentration of NDF was analyzed by adding heat-stable α-amylase and sodium sulfite with correction for insoluble ash. The gross energy (GE) of ingredients, diets, feces and urine were measured using an Automatic Isoperibol Oxygen Bomb Calorimeter (Parr 1281 Calorimeter; Parr Instrument Co., Moline, IL, USA). The analyzed chemical compositions of the diets are shown in Table 2.

2.6. *Calculations and statistical analyses*

The DE, ME and ATTD of chemical compositions in 5 treatment diets were calculated. Minerals and vitamins were assumed to have a negligible contribution to the digestibility of GE considering their small proportion (2.2%) in the experimental diets.

The DE and ME contents of the diets were calculated using the equations: $\mathrm{DE} = (\mathrm{GE_{in}} - \mathrm{GE_{out1}})/\mathrm{F_{in}}$, $\mathrm{ME} = (\mathrm{GE_{in}} - \mathrm{GE_{out2}})/\mathrm{F_{in}}$, where DE is the DE content in diets (MJ/kg), $\mathrm{GE_{in}}$ is the total GE intake (MJ), $\mathrm{GE_{out1}}$ is the GE content in feces (MJ), $\mathrm{GE_{out2}}$ is the GE content in feces and urine (MJ), $\mathrm{F_{in}}$ is the total feed intake (kg). The ATTD for DM, GE, EE, ADF, NDF and CP was calculated using the equation: $\mathrm{ATTD}\ (\%) = [(\mathrm{F_{in}} - \mathrm{F_{out}})/\mathrm{F_{in}}] \times 100$, where ATTD is the apparent total tract digestibility of DM (%), GE (%), EE (%), ADF (%), NDF (%) and CP (%), $\mathrm{F_{in}}$ is the total intake of DM (g), GE (kcal), EE (g), ADF (g), NDF (g) and CP (g) from d 8 to 12, and $\mathrm{F_{out}}$ is the total fecal output of DM (g), GE (kcal), EE (g), ADF (g), NDF (g) and CP (g) originating from the feed that was fed from d 8 to 12. The DE and ME contents of konjac flour residues and ramie were calculated according to the difference methods (Adeola, 2001).

Data were checked for normality and outliers were detected using the UNIVARIATE procedure of SAS (SAS Institute, Cary, NC). No outliers were identified. Data were then analyzed by one-way ANOVA using the PROC GLM procedure of SAS (SAS Institute). Pig was treated as the experimental unit, and dietary treatment was the only fixed effect included in the model. Treatment means were calculated using the LSMEANS statement, and statistical differences among the treatments were separated by the Tukey's test. Statistical significance was declared at $P < 0.05$.

3. Results

3.1. *Fecal output, DE and ME content of diets*

The effects of fibre sources (konjac flour residues vs. ramie) on fecal moisture content, fecal wet weight and fecal dry weight are shown in Table 3. Compared with the CTL group, 4 fibre groups showed greater fecal wet weight and fecal dry weight ($P < 0.05$). Among the 4 fibre groups, pigs fed the HK diet had the greatest fecal wet weight, and pigs fed the HK and HR diets had greater fecal dry weight compared with other groups. There was no difference in fecal wet weight and fecal dry weight between the LK group and the LR group. Moreover, the HK and LK groups showed an increase in fecal moisture content compared with the LR, HR, and CTL groups ($P < 0.05$).

The energy values of the 5 diets are shown in Table 4. The GE contents among the 5 diets were: HR > LR > CTL > LK > HK ($P < 0.01$). The fecal energy values of HK and HR groups were higher ($P < 0.01$) than those of other groups. No significant differences were observed in urinary energy value among the 5 treatment groups. The LK, HK and HR diets had lower ($P < 0.01$) DE values compared with the CTL diet, and the HR diet had greater ($P < 0.01$) DE value compared with the HK diet. The HK diet showed the lowest ($P < 0.01$) ME value among the 5 diets, and the HR diet showed lower ($P < 0.01$) ME value compared with the CLT diet. The ME:DE ratio was lower ($P < 0.01$) in the HK diet compared with the LK diet.

3.2. *Apparent total tract digestibility of nutrients in diets*

The ATTD of nutrients are shown in Table 5. The ATTD of DM, GE and CP were greater ($P < 0.01$) in the CTL diet compared with the

Table 3
Effects of konjac flour residues and ramie in diets fed to growing pigs on fecal output.

Item	Treatments[1]					SEM	*P*-value
	CTL	LK	HK	LR	HR		
Feed intake, g/d	1,700.60	1,691.83	1,628.87	1,673.13	1,696.57	62.12	0.92
Fecal wet weight, g/d	459.43^{d}	597.37^{c}	834.07^{a}	637.67^{c}	782.97^{b}	57.85	<0.01
Fecal dry weight, g/d	159.47^{c}	199.67^{b}	259.99^{a}	222.74^{b}	268.46^{a}	17.30	<0.01
Fecal moisture, %	65.29^{c}	66.58^{b}	68.83^{a}	65.06^{c}	65.71^{c}	0.31	<0.01

$^{a\text{-}d}$ Means within a row with unlike superscript letters were significantly different ($P < 0.05$).

[1] CTL: corn-soybean basal diet; LK: diets containing 15% of konjac flour residues; HK: diets containing 30% of konjac flour residues; LR: diets containing 15% of ramie; HR: diets containing 30% of ramie.

Table 4
Effects of konjac flour residues and ramie in diets fed to growing pigs on energy values.

Item	Treatments[1]					SEM	*P*-value
	CTL	LK	HK	LR	HR		
GE, MJ/kg	16.55^{c}	16.38^{d}	16.15^{e}	17.05^{b}	17.20^{a}	0.01	<0.01
FE, MJ/kg	1.76^{c}	2.10^{c}	2.74^{a}	2.53^{b}	3.01^{a}	0.16	<0.01
UE, MJ/kg	0.43	0.34	0.42	0.38	0.38	0.03	0.26
DE, MJ/kg	14.79^{a}	14.28^{b}	13.41^{c}	14.52^{ab}	14.19^{b}	0.16	<0.01
ME, MJ/kg	14.35^{a}	13.94^{ab}	12.99^{c}	14.13^{ab}	13.81^{b}	0.16	<0.01
ME:DE, %	97.06^{ab}	97.63^{a}	96.90^{b}	97.35^{ab}	97.31^{ab}	0.23	<0.01

GE = gross energy; FE = fecal energy; UE = urinary energy; DE = digestible energy; ME = metabolizable energy; ME:DE = the ratio of ME to DE.

$^{a-e}$ Means within a row with unlike superscript letters were significantly different ($P < 0.05$).

[1] CTL: corn-soybean basal diet; LK: diets containing 15% of konjac flour residues; HK: diets containing 30% of konjac flour residues; LR: diets containing 15% of ramie; HR: diets containing 30% of ramie.

Table 5
Effects of konjac flour residues and ramie in diets fed to growing pigs on apparent total tract digestibility (ATTD) of various nutrient components (%).

Item	Treatments[1]					SEM	*P*-value
	CTL	LK	HK	LR	HR		
DM	89.63^{a}	87.00^{b}	82.70^{c}	85.41^{b}	82.85^{c}	0.85	<0.01
OM	91.16^{a}	88.86^{b}	85.33^{c}	86.92^{b}	84.51^{c}	0.84	<0.01
GE	89.38^{a}	87.18^{b}	83.02^{c}	85.15^{b}	82.49^{c}	0.96	<0.01
CP	89.64^{a}	84.12^{b}	75.72^{c}	83.86^{b}	79.93^{c}	1.53	<0.01
EE	42.26^{b}	58.65^{a}	35.93^{c}	62.06^{a}	62.04^{a}	3.17	<0.01
NDF	58.40	62.71	61.05	63.07	65.78	2.26	0.25
ADF	72.01	63.26	72.42	66.89	62.57	4.13	0.31

DM = dry matter; OM = organic matter; GE = gross energy; CP = crude protein; EE = ether extract; NDF = neutral detergent fibre; ADF = acid detergent fibre.

$^{a-c}$ Means within a row with unlike superscript letters were significantly different ($P < 0.05$).

[1] CTL: corn-soybean basal diet; LK: diets containing 15% of konjac flour residues; HK: diets containing 30% of konjac flour residues; LR: diets containing 15% of ramie; HR: diets containing 30% of ramie.

other 4 fibre diets. The ATTD of DM, OM, GE and CP were also greater ($P < 0.01$) in the LK and LR diets compared with those in the HK and HR diets. The ATTD of EE was the lowest ($P < 0.01$) in the HK diet among the 5 diets. The ATTD of EE was greater ($P < 0.01$) in the LK, LR and HR diets compared with the CTL diet. No significant difference was observed in the ATTD of NDF and ADF among the 5 diets.

3.3. *DE and ME contents of konjac flour residues and ramie*

In our experiment, the DE and ME values of konjac flour residues under 15% or 30% inclusion were 11.66, 11.87 MJ/kg and 10.41, 10.03 MJ/kg, respectively. The corresponding DE and ME values for ramie were 13.27, 13.16 MJ/kg and 13.07, 12.82 MJ/kg, respectively. Compared with konjac flour residues, ramie has greater DE and ME values under the same inclusion level ($P < 0.05$). The above results are shown in Table 6.

Table 6
The DE and ME contents in konjac flour residues and ramie fed to growing pigs.

Item	Treatments[1]				SEM	*P*-value
	LK	HK	LR	HR		
DE, MJ/kg	11.66^{b}	10.41^{b}	13.27^{a}	13.07^{a}	0.66	0.02
ME, MJ/kg	11.87^{b}	10.03^{b}	13.16^{a}	12.82^{a}	0.66	0.01
ME:DE, %	99.98	96.40	99.37	97.86	1.33	0.04

DE = digestible energy; ME = metabolizable energy; ME:DE = the ratio of ME to DE.

$^{a-b}$ Means within a row with unlike superscript letters were significantly different ($P < 0.05$).

[1] LK: diets containing 15% of konjac flour residues; HK: diets containing 30% of konjac flour residues; LR: diets containing 15% of ramie; HR: diets containing 30% of ramie.

4. Discussion

Fibre-containing diets could increase fecal output (Hansen et al., 2007), and the fecal weight varied widely from the type and quantity of dietary fibre (Shankardass et al., 1990). Fibres used in our experiment are from different botanical origins and have different TDF compositions. Ramie has a typical IDF content, while konjac flour has a relatively high SDF content. Renteria-Flores et al. (2008) reported that elevated intake of IDF increased excretion of fecal DM, whereas elevated intake of SDF had no effect on fecal output, because 50% to 60% of the dry matter excretion at the rectum was IDF (Wilfart et al., 2007). However, in our study, the output of feces increased as the intake of both konjac flour residues and ramie increased, which is consistent with the results from Zhang et al. (2013). The increased fecal output with greater inclusion level of dietary konjac flour residues in our experiment could be explained by the increased moisture content in feces. The chemical composition analysis showed that the ratio of IDF to SDF was approximately 1:1 for konjac flour residues, and the SDF component in konjac flour residues had a stronger water-holding capacity (Serena et al., 2008), resulting in large amount of moisture remaining in feces.

Digestible energy and ME are 2 major components for evaluating the energy values of swine diet. Dietary excess fibre exhibits an adverse effect on the DE value in pigs (Noblet and Perez. 1993). Bash Knudsen (2001) reported a strong negative relationship between dietary fibre level and net energy, which is similar to our results that the DE and ME contents in diets with low inclusion level of dietary fibre (konjac flour residues and ramie) were significantly increased compared with dietary high fibres. The negative effect may be caused by the indigestible cell wall materials (lignin, cellulose and non-cellulosic polysaccharides) in dietary fibre (Bash Knudsen, 2001). Moreover, the averaged ME:DE ratio in the 4 fibre diets observed in our experiment was 0.973, which was in agreement with the work of Zhang et al. (2013), who reported that the ratio of ME to DE of fibre diets was approximately 0.97.

The ATTD of DM, OM, GE, and CP decreased as the dietary level of both konjac flour residues and ramie increased in diets. Our results were in agreement with reports by Olesen et al. (2001), who showed that the digestibility of DM, OM, CP, and energy were negatively affected by the intake level of TDF. Some previous research also had shown a similar effect of dietary fibre on apparent digestibility of energy in growing pigs (Kennelley and Aherne, 1980; Chabeauti et al., 1991). Renteria-Flores et al. (2008) reported that SDF and IDF had different effects on nutrient digestibility. Increased SDF intake improved the digestibility of energy and NDF, while increased IDF intake decreased the digestibility of energy, N, and SDF, with no effect on NDF digestibility. The SDF-related results were not observed in our study on konjac flour residues, which might be due to only approximately 50% SDF compositions in konjac flour residues diets. The effect of IDF on nutrient digestibility can be partly explained by the increased rate of digesta passage through the digestive tract. The fibre components in plant cell walls could hinder the access of digestive enzymes to the cell contents, which greatly influences the digestion of feed (Bash Knudsen, 2001). In addition, Serena et al. (2008) reported that SDF had a high water-holding capacity, which delayed gastric emptying, slowed the rate of nutrient absorption, and negatively affected the digestibility of dietary components.

An increased ATTD of EE in diets containing ramie or low inclusion level of konjac flour residues was observed compared with the basal diet, but the ATTD of EE decreased in diets containing high inclusion level of konjac flour residues. Dietary fibre widely involves in fat digestion, and several hypotheses was raised to explain the underlying mechanisms. For example, dietary fibre was reported to stimulate endogenous secretion, increase digesta viscosity, and improve bile acid binding capacity (Dégen et al., 2007). Our results agreed with the observations from Liu et al. (2016), but was different from other previous studies that reported decreased apparent digestibility of fat as IDF supply increased (Bakker, 1996; Hansen et al., 2006). The reason for the increased ATTD of EE in LR and HR diets may be related to the relative high EE content in ramie. The ATTD of lipids can increase with the increased concentration of dietary fat, since endogenous amount of fat exerts a stronger influence on the apparent fat digestibility at low dietary levels than at higher levels (Just, 1982; Jørgensen et al., 1993). Anderson et al. (1994) observed an increase in fecal bile acid excretion in rats fed soluble fibre compared with insoluble fibre, indicating that soluble fibre had larger impact on fat digestion than insoluble fibre. Moreover, Högberg and Lindberg (2004) found that improving the solubility of dietary fibre significantly increased the total tract digestibility of fat in pig, which is inconsistent with our results. Although SDF can potentially increase the viscosity of digesta in the LK diet, pigs with large volume of the gastrointestinal tract can drink large amount of water, resulting in dilution of the digesta viscosity (Sun et al., 2015). However, in pigs fed the HK diet, SDF may largely increase the digesta viscosity, affecting the physiology and ecosystem of the gut (Choct et al., 1996), thus reducing the interaction between substrate and digestive enzymes or effective absorption of nutrients. The increased inclusion level of SDF in diets can reduce the flow rate of digesta, and may increase the microbial colonization in the small intestine, which not only undergoes self-fermentation, but also competes with the host in utilization of nutrients such as carbohydrates and proteins (Choct et al., 1996). In addition, enzymes secreted by some microbes can cause degradation of bile acids, leading to reduced lipid digestion and absorption (Smits et al., 1998).

In this study, we firstly evaluated the energy values and nutrient digestibility of 2 uncommon fibre sources — konjac flour residues and ramie. Konjac blends were widely used to improve the textural characteristics of low-fat meat emulsion products (Chin et al., 1998). The foliage of ramie, also known as “China grass”, is very palatable and has been proved to be suitable not only for ruminant but also for pig and poultry feed. Therefore, the DE and ME values determined in our study are beneficial to the better utilization of konjac flour residues and ramie in the future.

5. Conclusions

The differences in fecal moisture content and the ATTD of EE among the 5 diets were mainly due to the different chemical compositions of konjac flour residues and ramie. Compared with konjac flour residues, ramie has greater DE and ME values under the same inclusion level.

Competing interests

The authors declare that they have no competing interests.

Acknowledgments

This research was financially supported by the Chinese Universities Scientific FundChinese Universities Scientific Fund (2017QC040) and the 111 Project (B16044).

References

Adeola O. Digestion and balance techniques in pigs. In: Lewis AJ, Southern LL, editors. Swine nutrition. 2nd ed. 2001. p. 903–16.

Anderson JW, Jones AE, Riddell-Mason S. Ten different dietary fibres have significantly different effects on serum and liver lipids of cholesterol-fed rats. J Nutr 1994;124:78–83.

AOAC. Official methods of analysis. 18th ed. Gaithersburg, MD: Association of Official Analytical Chemists International; 2007.

Bakker G. Interaction between carbohydrates and fat in pigs-Impact on energy evaluation of feeds. 1996.

Bash Knudsen KE. The nutritional significance of “dietary fibre” analysis. Anim Feed Sci Tech 2001;90:3–20.

Boudry G, Péron V, Le Huërou-Luron I, Lallès JP, Sève B. Weaning induces both transient and long-lasting modifications of absorptive, secretory, and barrier properties of piglet intestine. J Nutr 2004;134:2256–62.

Chin KB, Keeton JT, Longnecker MT, Lamkey JW. Low-fat bologna in a model system with varying types and levels of konjac blends. J Food Sci 1998;63:808–13.

Chabeauti E, Noblet J, Carré B. Digestion of plant cell walls from four different sources in growing pigs. Anim Feed Sci Technol 1991;32:207–13.

Choct M, Hughes RJ, Wang J, Bedford MR, Morgan AJ, Annison G. Increased small intestinal fermentation is partly responsible for the anti-nutritive activity of non-starch polysaccharides in chickens. Br Poultry Sci 1996;37:609–21.

Dégen L, Halas V, Babinszky L. Effect of dietary fibre on protein and fat digestibility and its consequences on diet formulation for growing and fattening pigs: a review. Acta Agric Scand Suppl A 2007;57:1–9.

Guerin S, Ramonet Y, LeCloarec J, Meunier-Salaün P, Bourguet Malbert CH. Changes in intragastric meal distribution are better predictors of gastric emptying rate in conscious pigs than are meal viscosity or dietary fibre concentration. Brit J Nutr 2001;85:343–50.

Hansen MN, Kai P, Møller HB. Effects of anaerobic digestion and separation of pig slurry on odor emission. Appl Eng Agric 2006;22:135–9.

Hansen MJ, Chwalibog A, Tauson AH. Influence of different fibre sources in diets for growing pigs on chemical composition of faeces and slurry and ammonia emission from slurry. Anim Feed Sci Technol 2007;134:326–36.

Högberg A, Lindberg JE. Influence of cereal non-starch polysaccharides on digestion site and gut environment in growing pigs. Livest Prod Sci 2004;87:121–30.

Högberg A, Lindberg JE. The effect of level and type of cereal non-starch polysaccharides on the performance, nutrient utilization and gut environment of pigs around weaning. Anim Feed Sci Technol 2006;127:200–19.

Huang Q, Shi CX, Su YB, Liu ZY, Li DF, Liu L, et al. Prediction of the digestible and metabolizable energy content of wheat milling by-products for growing pigs from chemical composition. Anim Feed Sci Technol 2014;196:107–16.

Johansen HN, Knudsen KEB, Sandström B, Skjoth F. Effects of varying content of soluble dietary fibre from wheat flour and oat milling fractions on gastric emptying in pigs. Brit J Nutr 1996;75:339–51.

Just A. The net energy value of crude fat for growth in pigs. Livest Prod Sci 1982;9:501–9.

Jørgensen H, Jakobsen K, Eggum BO. Determination of endogenous fat and fatty acids at the terminal ileum and on faeces in growing pigs. Acta Agric Scand A-Anim Sci 1993;43:101–6.

Kipriotis E, Heping X, Vafeiadakis T, Kiprioti M, Alexopoulou E. Ramie and kenaf as feed crops. Ind Crop Prod 2015;68:126–30.

Kennelly JJ, Aherne FX. The effect of fibre in diets formulated to contain different levels of energy and protein on digestibility coefficients in swine. Can J Anim Sci 1980;60:717–26.

Li PL, Wu F, Chen YF, Wang JR, Guo PP, Li ZC, et al. Determination of the energy content and amino acid digestibility of double-low rapeseed cakes fed to growing pigs. Anim Feed Sci Technol 2015;210:243–53.

Liu Q, Zhang WM, Zhang ZJ, Zhang YJ, Zhang YW, Chen L, et al. Effect of fibre source and enzyme addition on the apparent digestibility of nutrients and physicochemical properties of digesta in cannulated growing pigs. Anim Feed Sci Technol 2016;216:262–72.

NRC. Nutrient requirements of swine. 10th rev. ed. Washington, DC: Natl. Acad. Press; 2012.

Noblet J, Perez JM. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J Anim Sci 1993;71:3389–98.

Noblet J, Le Goff G. Effect of dietary fibre on the energy value of feeds for pigs. Anim Feed Sci Technol 2001;90:35–52.

Owusu-Asiedu A, Patience JF, Laarveld B, Van Kessel AG, Simmins PH, Zijlstra RT. Effects of guar gum and cellulose on digesta passage rate, ileal microbial populations, energy and protein digestibility, and performance of grower pigs. J Anim Sci 2006;84:843–52.

OECD-FAO. Agricultural outlook. Paris, France: OECD Publishing; 2015.

Olesen CS, Jørgensen H, Danielsen V. Effect of dietary fibre on digestibility and energy metabolism in pregnant sows. Acta Agric Scand, Sect A-Anim Sci 2001;51:200–7.

Renteria-Flores JA, Johnston LJ, Shurson GC, Gallaher DD. Effect of soluble and insoluble fibre on energy digestibility, nitrogen retention, and fibre digestibility of diets fed to gestating sows. J Anim Sci 2008;86:2568–75.

Serena A, Jørgensen H, Bach Knudsen KE. Digestion of carbohydrates and utilization of energy in sows fed diets with contrasting levels and physicochemical properties of dietary fibre. J Anim Sci 2008;86:2208–16.

Shankardass K, Chuchmach S, Chelswick K, Stefanovich C, Spurr S, Brooks J, et al. Bowel function of long-term tube-fed patients consuming formulae with and without dietary fibre. J Parenter Enteral Nutr 1990;14:508–12.

Sun HQ, Tan CQ, Wei HK, Zou Y, Long G, Ao JT, et al. Effects of different amounts of konjac flour inclusion in gestation diets on physio-chemical properties of diets, postprandial satiety in pregnant sows, lactation feed intake of sows and piglet performance. Anim Reprod Sci 2015;152:55–64.

Smits CH, Veldman A, Verkade HJ, Beynen AC. The inhibitory effect of carboxymethylcellulose with high viscosity on lipid absorption in broiler chickens coincides with reduced bile salt concentration and raised microbial numbers in the small intestine. Poult Sci 1998;77:1534–9.

Van Soest PJ, Robertson JB, Lewis BA. Methods for dietary fibre and non-starch polysaccharides in relation to animal nutrition. J Dairy Sci 1991;74:3568–97.

Wilfart A, Montagne L, Simmins H, Noblet J, Van Milgen J. Effect of fibre content in the diet on the mean retention time in different segments of the digestive tract in growing pigs. Livest Sci 2007;109:27–39.

Wenk C. The role of dietary fibre in the digestive physiology of the pig. Anim Feed Sci Technol 2001;90:21–3.

Yin YL, Zhong HY, Huang RL, Chen CM, Li TJ, Pai YF. Nutritive value of feedstuffs and diets for pigs. I. Chemical composition, apparent ileal and fecal digestibility. Anim Feed Sci Technol 1993;44:1–27.

Yin YL. Nutritive value of feedstuffs and diets for pigs, II. Apparent post-ileal digestibility and interrelationship between dietary constituents and fecal and ileal digestibility. Anim Feed Sci Technol 1994;45:243–55.

Yin YL, Deng ZY, Huang HL, Zhong HY, Hou ZP, Gong J, et al. Nutritional and health function of carbohydrate for pigs. J Anim Feed Sci 2004;13:523–38.

Zhang WJ, Li DF, Liu L, Zang JJ, Duan QW, Yang WJ, et al. The effects of dietary fibre level on nutrient digestibility in growing pigs. J Anim Sci Biotechnol 2013;4:1–7.