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

A R T I C L E   I N F O

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

A B S T R A C T

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.

© 2018, Chinese Association of Animal Science and Veterinary Medicine. Production and hosting by Elsevier B.V. on behalf of KeAi Communications Co., Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

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...
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 residues and ramie by now. Therefore, the objectives of this study were to: 1) evaluate the effects of konjac flour residues and ramie on 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).
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 was 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 sulfoxide and cysteic acid using an Amino Acid Analyzer (Hitachi L-8800, Tokyo, Japan). The dry matter (method 934.01), ether extract (method 920.39) and crude protein (method 990.03) of the feed that was fed from d 8 to 12. The DE and ME contents of the diets and urine (MJ), $F_{in}$ is the total feed intake (kg). The ATTD for DM, GE, EE, ADF, NDF, CP and $F_{out}$ was calculated using the equation: $A T T D \% = \left( F_{in} - F_{out}\right)/F_{in} \times 100$, where ATTD is the apparent total tract digestibility of DM (%), GE (%), EE (%), ADF (%), NDF (%) and CP (%), $F_{in}$ is the total intake of DM (g), GE (kcal), EE (g), ADF (g), NDF (g) and CP (g) from d 8 to 12, and $F_{out}$ 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: $H R > L R > C T L > L K > H K$ ($P < 0.01$). 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 HK, 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 CTL diet. The ME:DE ratio was lower ($P < 0.01$) in the HK diet compared with the LR 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

| Item                  | Treatments $^1$ | CTL          | LK          | HK          | LR          | HR          | SEM   | $P$-value |
|-----------------------|-----------------|--------------|-------------|-------------|-------------|-------------|-------|-----------|
| 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       | 597.37      | 834.07      | 637.67      | 782.97      | 57.85 | <0.01     |
| Fecal dry weight, g/d |                 | 159.47       | 199.67      | 259.99      | 222.74      | 268.46      | 17.30 | <0.01     |
| Fecal moisture, %     |                 | 65.29        | 66.58       | 68.83       | 65.06       | 65.71       | 0.31  | <0.01     |

$^a,b$ 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.
Discussion

The quantity of dietary 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 compositions of konjac flour residues 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 diets. 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 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 (Kenneley 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 inclusions 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 (Degen 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; Jorgensen 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, Hogberg 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 IDF can potentially increase the viscosity of digesta in the UK 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 (Chot 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 (Chot 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

Adedapo O. Digestion and balance techniques in pigs. In: Lewis AJ, Southern LL, editors. Swine nutrition. 2nd ed. London: Elsevier Science Ltd; 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. Gathersburg, 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 DE. The nutritional significance of “dietary fibre” analysis. Anim Feed Sci Tech 2001;90:3–20.
Boudry G, Péron V, Le Huerou-Luron I, Lalles JP, Sève B. Weaning induces both transient and long-lasting modifications of absorptive, secretory, and barrier functions of piglet intestine. J Nutr 2004;134:2256–62.
Chen 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.
Chabauti E, Noblet J, Carre B. Digestion of plant cell walls from four different sources in growing pigs. Anim Feed Sci Technol 1991;2:207–13.
Chot 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 1997;36:609–21.
Degen L, Halas V, Babinsky J. Dietary fibre composition of dietary fibre crops with different 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 gastrointestinal meal size affect the potentiality 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 anaeroic digestion and separation of pig residues was observed compared with insoluble fibre. Dietary fibres have larger impact on fat digestion than insoluble fibre. Moreover, Hogberg 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 IDF can potentially increase the viscosity of digesta in the UK 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 (Chot 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 (Chot 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).
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 BL, 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.