Nutrient profile and digestibility of tubers and agro-industrial coproducts determined using an in vitro model of swine

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ABSTRACT

Exploring and evaluating alternative feed ingredients to be used in swine diet is essential due to highly variable cost and limited availability of conventional feed ingredients. Tubers and agro-industrial coproducts could provide the basis for producing affordable swine feed. However, information on the nutritional value of these potential alternative feedstuffs is necessary while considering their use in swine feeding program. Four tubers (purple sweet potato [PSP], okinawan sweet potato, taro and cassava) and 3 coproducts (okara, wheat millrun [WMR] and barley brewers grain [BBG]) were analyzed for their proximate nutrients, starch, fibers and gross energy (GE) content. Two independent in vitro studies were carried out for tubers and coproducts to determine their nutrients digestibility using a 3-step enzymatic assay (which mimics the digestion occurring in the gastrointestinal tract of swine) with 9 replicates of each sample digested in 3 batches equally. All replicate samples were used to determine in vitro dry matter digestibility (IVDDM) while 2 replicates from each batch were used to determine in vitro GE digestibility (IVDGE). Among tubers, CP content was the highest in taro (8.8%) and the lowest in cassava (3.7%), while CP content among coproducts was the highest in okara (22.7%) and the lowest in WMR (11.8%). Ether extract content among tubers ranged from 1.1% to 2.8%. The GE content among tubers, ranged from 4,134 to 4,334 kcal/kg whereas among coproducts it ranged from 4,270 to 4,794 kcal/kg. Among tubers, IVDDM for PSP was significantly higher (86.8%, \(P < 0.001\)) than taro (70.3%). Among coproducts, IVDDM of okara (74.1%) was significantly higher (\(P < 0.05\)) than BBG (61.3%). In conclusion, both tubers and coproducts can be used as a partial substitute of conventional energy feedstuffs in swine diets as these are rich in GE and other nutrients and are fairly digestible.

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1. Introduction

Market availability of conventional feedstuffs like corn, wheat and soybean meal (SBM) are quite variable and their price fluctuates depending on production and their demand for human and livestock consumption and biofuel production. Including alternative feedstuffs in the swine diets has the potential not only to support the swine industry economically but also enhancing the environmental sustainability. This is particularly true for places where the conventional feedstuffs cannot be grown or destined cost-effectively to swine feeding. In such case, alternative feeding systems need to be developed and evaluated, which can partially or completely replace the inclusion of conventional feedstuffs in swine diets. Potential alternative feedstuffs such as distillers dried grains with soluble (Avelar et al., 2010; Jha et al., 2013; Agyekum et al., 2014), oil seed cakes (Yin et al., 1994; Seneviratne et al., 2010), and wheat mill run (WMR) (Nortey et al., 2008; Jha et al., 2012) have been studied and are widely used in swine feeding program.

Tubers such as purple sweet potato (PSP), okinawan sweet potato (OSP), taro and cassava along with agro-industrial coproducts such as okara (coproduct from tofu making process), wheat mill run, and barley brewers grain (BBG) could together provide basis...
for producing more affordable locally manufactured feed for swine. Tubers are rich in starch and can serve as a good source of energy whereas coproducts are intermediate products with fair amount of energy and protein with high fiber content. Some of these agricultural products and coproducts are evaluated and used elsewhere. However, agro-climatic conditions and farming systems largely differ from location to location, which influences the nutritional profile of tubers and their utilization in animals. Additionally, processing conditions affect the nutritional value of coproducts. Thus, nutritional value of these tubers and coproducts from particular origin needs to be evaluated before being used in swine feed.

2. Materials and methods

2.1. Feed ingredients and nutritional analysis

Four tubers (PSP, OSP, cassava, and taro) and 3 coproducts (WMR, BBG, and okara) were obtained from a local market of Honolulu, HI, USA. All the tuber samples were chopped and dried in a hot air oven (135°C for 2 h) to get the dry matter. The dried samples were ground to pass through 1 mm screen using a laboratory Wiley mill (Thomas Scientific, Swedesboro, NJ, USA). The sub samples were further ground using 0.5 mm screen size for some nutritional analysis. Nutrient profile and in vitro digestibility of nutrients were determined using 1 mm size sample, while starch was determined using 0.5 mm size sample. Proximate analysis of the samples was conducted according to AOAC standard procedures (AOAC, 2006) with specific methods as follows: DM (135°C for 2 h, method 930.15), ash (method 942.05), CP using a LECO analyzer (LECO CN-2000, Leco Corp., St. Joseph, MI, USA), (method 976.05, CP = N × 6.25). Acid detergent fiber (ADF, method 973.18) and neutral detergent fiber (NDF, method 202.04) was determined using Ankom200 Fiber Analyzer (Ankom Technology, Macedon, NY, USA). Heat stable α-amylase and sodium sulfite was used for NDF determination. Total starch content (method 996.11) was determined using a commercial test kits (Megazyme Internation Ltd., Ireland, UK). Gross energy content was determined using an oxygen bomb calorimeter (Parr Isoperibol Bomb Calorimeter 6200, Parr Instrument Co., Moline, IL, USA).

2.2. In vitro digestion

Three steps in vitro enzymatic digestion technique (Boisen and Fernández, 1997) was used to determine the apparent total tract digestibility of DM and GE in swine. Briefly, 1 g of sample was weighed in a 250 mL conical flask. Then, 50 mL of phosphate buffer solution 1 (0.1 mol/L, pH 6.0) was added to the flask followed by 20 mL of HCl solution (0.2 mol/L). The pH was adjusted to 2.0 by mixing with 1 mol/L HCl or 1 mol/L NaOH. One milliliter of chloramphenicol (Sigma C-0378, Sigma–Aldrich Corp., St. Louis, MO, USA) solution was added to prevent bacterial growth, which might take place during hydrolysis. Two milliliter of freshly prepared pepsin (Sigma P-0609, 800–2,500 units/mg, Sigma–Aldrich Corp., St. Louis, MO, USA) solution was added to the flask. The pepsin solution was made by mixing 0.75 g of pepsin to 30 mL of ultra-pure water. The flask was then closed with a rubber stopper and incubated in a water bath at 39°C under gentle agitation (50 rpm) for 2 h. The 20 mL phosphate buffer solution 2 (0.2 mol/L, pH 6.8) and 10 mL of 0.6 mol/L NaOH was then added to the solution in the flask. The pH was adjusted to 6.8 with 1 mol/L HCl or 1 mol/L NaOH. Six milliliter of fresh pancreatin solution, made by mixing 3 g of pancreatin (Sigma P-1750, Sigma–Aldrich Corp., St. Louis, MO, USA) to 90 mL of ultrapure water, was added, and hydrolysis was continued under the same conditions for 4 h.

At the end of the of incubation, 20 mL of a 0.2 mol/L EDTA solution was added to the flask, and the pH was adjusted to 4.8 with a 30% acetic acid solution. Then 1 mL of Viscozyme (a multienzyme complex obtained from Aspergillus aculeatus containing cellulase, β-glucanase, arabinase, xylanase, mannanase, and pectinase; Novozymes, Bagsvaerd, Denmark) was added and the flask was incubated under same conditions for 18 h. The undigested residue was then collected in a filtration unit using a porcelain filtration funnel lined with pre-weighed filter paper (Whatman no. 54; Whatman Inc., Florham Park, NJ, USA). All the material was transferred with double distilled water to the funnel. The residue, along with the filter paper, was dried overnight at 80°C and weighed the next day.

Two independent studies of tubers and coproducts were carried out. The experimental scheme for the in vitro digestion was as follows:

- 4 tubers × 3 bottles repeated over 3 batches;
- 3 agro-industrial coproducts × 3 bottles repeated over 3 batches.

2.3. Calculations and statistical analyses

All replicate samples were used to determine in vitro dry matter digestibility (IVDDM) while 2 replicates from each batch were used to determine in vitro GE digestibility (IVDGE). The IVDDM and IVDGE were calculated as follows:

\[ \text{IVDDM} = \frac{\text{DWH} - \text{DWR}}{\text{DWH}} \times 100, \]

where DWH = Dry weight of sample before hydrolysis; DWR = Dry weight of residue.

\[ \text{IVDGE} = \frac{(\text{g sample} \times \text{DMs} \times \text{GEs}) - (\text{g residue} \times \text{GER})}{(\text{g sample} \times \text{DMs} \times \text{GEs})}, \]

where DMs = % Dry matter of sample; GEs = Gross energy of sample; GER = Gross energy of residue.

The digestible energy (DE) and metabolizable energy (ME) were calculated using equation number 24 and 45, respectively (Noblet and Perez, 1993) and net energy (NE) using equation number 11 (Noblet et al., 1994).

\[ \text{DE} = 4.162 - 9.4 \times \text{ash} + 2 \times \text{CP} + 3.9 \times \text{EE} - 2.7 \times \text{hemicellulose} - 4.5 \times \text{ADF}; \]

\[ \text{ME} = 0.997 \times \text{DE} - 0.68 \times \text{CP} + 0.23 \times \text{EE}; \]

\[ \text{NE} = 2.875 + 4.38 \times \text{EE} + 0.67 \times \text{starch} - 5.5 \times \text{ash} - 2.01 \times (\text{NDF} - \text{ADF}) - 4.02 \times \text{ADF}. \]

The IVDVM and IVDGE of feedstuffs were compared using the MIXED procedure of SAS (SAS v9.2, SAS Institute Inc., Cary, NC, USA), where feedstuffs were treated as fixed factor and batch as random factor. Means were separated using the Tukey method using pdmix macro of SAS. Differences were considered significant if \( P < 0.05 \).

3. Results and discussion

As shown in Table 1, CP content among tubers ranged from 3.7% to 8.8%. Taro contained the highest amount of CP (8.8%) and cassava had the lowest amount of CP (3.7%). Among coproducts, okara had the highest CP content (22.7%) and WMR had the lowest CP content.
The PSP had the highest amount of EE (2.8%) and cassava the lowest amount of EE (1.1%). The ADF content of tubers ranged from 5.7% to 10.4%, taro had the highest and PSP had the lowest. The ADF content of the coproducts ranged from 19.7% to 34.1% with the highest value for BBG and the lowest for okara. Both ADF and NDF content were higher in taro, whereas, NDF content in coproducts ranged from 31.0% to 42.1%. Crude protein content of both PSP and OSP was slightly lower than that reported (6.4%) by Dominguez (1992).

Table 2

| Feedstuff                   | DM | Ash | CP | EE | ADF | NDF | Hemi-cellulose | Starch | GE | DE | ME | NE |
|-----------------------------|----|-----|----|----|-----|-----|----------------|--------|----|----|----|----|
| Purple sweet potato         | 94.8 | 2.0 | 4.8 | 2.8 | 5.7 | 8.0 | 2.3            | 47.0   | 4,134 | 4,135 | 4,120 | 2,882 |
| Okinawa sweet potato       | 94.5 | 2.8 | 5.3 | 2.0 | 8.1  | 9.7 | 1.5            | 51.7   | 4,154 | 4,116 | 4,100 | 2,869 |
| Taro                       | 97.7 | 2.4 | 8.8 | 1.9 | 10.4 | 11.5 | 1.1            | 48.4   | 4,333 | 4,117 | 4,099 | 2,860 |
| Cassava                    | 89.3 | 4.1 | 3.7 | 1.1 | 6.5  | 11.3 | 4.8            | 60.9   | 4,193 | 4,095 | 4,080 | 2,863 |
| Wheat millrun              | 96.7 | 1.8 | 11.8 | 4.1 | 24.2 | 35.0 | 10.8           | 56.4   | 4,794 | 4,049 | 4,029 | 2,803 |
| Barley brewers grain       | 97.1 | 8.7 | 15.9 | 1.8 | 34.1 | 42.1 | 8.0            | 46.7   | 4,270 | 3,947 | 3,924 | 2,715 |
| Okara                      | 92.7 | 5.2 | 22.7 | 13.7| 19.7 | 31.0 | 11.3           | 61.2   | 4,707 | 4,095 | 4,071 | 2,847 |

DM = dry matter; CP = crude protein; EE = ether extract; ADF = acid detergent fiber; NDF = neutral detergent fiber; GE = gross energy; DE = digestible energy; ME = metabolizable energy; NE = net energy.

1 Values presented as kcal/kg.
2 Digestible energy and ME were calculated using equation number 24 and 45, respectively (Noblet and Perez, 1993).
3 Net energy was calculated using equation number 11 (Noblet et al., 1994).

Table 2

| Variable                  | Sample replicate | Purple sweet potato | Okinawa sweet potato | Taro | Cassava | SEM | P-value |
|---------------------------|------------------|--------------------|----------------------|------|---------|-----|---------|
| Dry matter                | 9                | 86.8               | 81.6                 | 70.3 | 82.1    | 0.010 | <0.0001 |
| Gross energy              | 6                | 87.5               | 82.3                 | 64.9 | 83.1    | 0.011 | <0.0001 |

*ab* Means with different superscripts within the columns are significantly different (P < 0.05).

Table 3

| Variable                  | Sample replicate | Wheat mill run | Barley brewers grain | Okara | SEM | P-value |
|---------------------------|------------------|----------------|----------------------|-------|-----|---------|
| Dry matter                | 9                | 69.9            | 61.3                 | 74.1  | 0.009 | <0.0001 |
| Gross energy              | 6                | 53.0            | 43.0                 | 66.2  | 0.015 | <0.0001 |

*ab* Means with different superscripts within the columns are significantly different (P < 0.05).
especially in young piglets. However, it can serve as an important source of energy feedstuff in places where it is largely produced and its digestibility can be increased by peeling off the outermost skin which is more fibrous.

The IVDDM of okara was fairly high (74.1%), which implies that 74% of nutrients in okara will be available to pigs upon its ingestion. The DE content of okara in this study was higher than SBM and expeller pressed canola meal (3,919 and 3,752 kcal/kg, respectively) (Seneviratne et al., 2010). Similarly, NE value of okara was higher than SBM (2,210 kcal/kg) and expeller pressed canola meal (2,550 kcal/kg; Seneviratne et al., 2010). This higher DE and NE value of okara may have resulted due to the higher EE content. Each 1% increase in dietary fat causes an increase in the average daily gain by 2% in grower pigs and 1% in finisher pigs (DeRouchey, 2007).

4. Conclusions

Tubers and coproducts, both are rich in energy and other nutrients. Both IVDDM and IVDGE vary among tubers. The PSP had the highest in vitro digestibility of all nutrients, while taro had the lowest. Cassava and okinawan sweet potato had similar in vitro DM and GE digestibility. Coproducts are rich in fiber, protein as well as other nutrients. The IVDDM was higher in okara, whereas IVDDM of BBG and WMR were almost the same. Tubers can be used as a partial substitute of common energy ingredients in pig diets, especially for subsistent farming system where these products are grown and are widely available whereas coproducts can also be used to replace traditional feed ingredients to some extent and can serve as potential source of protein as well as energy. All the tubers and co-products studied showed a potential to be used in swine diet but these feedstuffs need to be subjected to animal trials to have a better idea about in vivo digestibility, inclusion percentage and palatability or the voluntary feed intake by animals.

Conflict of interest statement

We certify that there is no conflict of interests with any financial, professional or personal that might have influenced the performance or presentation of the work described in this manuscript.

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