Potential impacts of guava seed meal on piglet feeding as a dietary fibre alternative

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ABSTRACT

The aim of this study was to determine the nutritional-energetic value of guava seed meal (GSM) for piglets in the starter phase and its effects on feed digestibility, growth performance, plasma parameter and diarrhea incidence. Assay I (digestibility testing) involved 16 entire male piglets with average initial body weight of 18.91 ± 3.6 kg distributed in a randomized block design, allocated to two treatments with eight replications. Treatments consisted of a reference diet and a test diet with a 20% replacement by GSM. In assay II (performance testing), 128 entire male piglets and average initial body weight of 14.47 ± 2.09 kg were distributed in a randomized block design, with four treatments repeated four times in two blocks. Treatments consisted of increasing levels of GSM (0%, 5%, 10%, 15%). Values higher were found for glutamine and arginine. The high GE value of the GSM was reflected in an elevated AMCGE of the feed, with greater DM and CP digestibility. There was difference (P < 0.05) for average daily feed intake, feed conversion ratio, urea and diarrhea. In conclusion, GSM does not affect apparent nutrient digestibility, and it promotes greater feed intake up to 10% inclusion and 15% improves diarrhea incidence.

1. Introduction

In order to reduce the costs of feeding piglets in the starter phase, it is necessary to search for alternative food ingredients and nutritional strategies, such as knowledge of the nutritional values of each ingredient to be used in animal nutrition, so that they contribute to the effective functioning of the gastrointestinal tract, favouring the growth performance of pigs (Pascoal et al. 2012).

Residues from the fruit industries have been indicated as possible replacements for protein and energy ingredients in animal feeding (Furlan et al. 2001). Moreover, their use in animal production arises as a possibility to reduce the problems of eliminating these residues and environmental contamination. However, when referring to non-ruminant animals, the use of these residues is not yet well clarified due to the lack of knowledge of their nutritional value, composition and appropriate inclusion levels in animal nutrition (Lousada Júnior et al. 2006).

Several fruit residues, such as barbados cherry, passion fruit, mango and tamarind can be incorporated into the animal feed, including the guava (Psidium guajava L.). However, there is no conformity in the literature on the chemical composition, constitution and percentage of the fruit that is not commercialized. Georganas et al. (2020) reported that the residues contain an expressive amount of nutrients that are wasted, as well as considerable amounts of fibrous matter and bioactive compounds. Psidium guajava L. is rich in fibrous material, so that the components of dietary fibre in the small intestine are minimally digested, providing a substrate for microbial fermentation in the large intestine (Budiño et al. 2015; Jarrett and Ashworth 2018). The main end products of this fermentation are short chain fatty acids (Budiño et al. 2015). Thus, the dietary fibre used during the starter phase of piglets can promote several processes such as the modulation of intestinal microbiota, serve as substrate for microbial fermentation, production of organic acids, differences in the viscosity of the intestinal digesta and influence on the development and size of the digestive organs, as well as intestinal histology (Jarrett and Ashworth 2018).

Information on the use of guava seed meal (GSM) in pigs feeding is scarce, allowing the assessment of its potential in order to verify the adequate inclusion level, as well as to quantify the biological responses of the animals. Studies evaluating the use of dietary fibres in pig nutrition have been reported (Ziemer et al. 2012; Fachinello et al. 2015; Navarro et al. 2018).

According to the protein and energy levels in the chemical composition of GSM, our hypothesis was that GSM can be used in pig feed without affecting the growth performance of the animals. In view of the above, the aim of this study was to determine the nutritional-energetic value of guava seed meal for piglets in the starter phase and its effects on feed digestibility, growth performance, plasma parameters and diarrhea incidence.

2. Materials and methods

The experiments were conducted in the Swine Sector of the Experimental Station Nucleus of the State University of...
Western Paraná (UNIOESTE). All procedures involving the animals were approved by CEUA/UNIOESTE, under protocol number 77/17, being in compliance with the Brazilian guidelines for the care and handling of animals used for scientific purposes.

2.1. Procedure for obtaining and analysing guava seed meal

The GSM was obtained from an industry producing fruit bran – NUTRA, located in the municipality of Dracena – SP, Brazil. After drying in a forced ventilation oven (105°C) for a period of 16 h and grinding, a sample was sent to the Animal Nutrition laboratory of the UNIOESTE for physicochemical assessment of the composition. The contents of dry matter (DM), organic matter (OM), mineral matter (MM), gross energy (GE), crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined according to methodologies described by AOAC (2005).

The total carbohydrate (TC) content was calculated according to the equations indicated by Sniffen et al. (1992). Starch and ether extract (EE) analyses were performed in the ABC Foundation laboratory, following the enzymatic method for starch analysis, in which alpha-amylase and glucoamylase enzymes were used and performed readings in UV-VIS spectrophotometer (Foss manufacturer, NIRSystems XDS, Rapid Content Analyzer model; Castro, PR, Brazil) at 520 nm following the methodology described by AOAC (2005). The EE determination was performed according to the Soxhlet extraction method. The aminogram and tannin determination of the GSM were performed by the CBO laboratory according to the methodology described at the Brazilian Compendium of Animal Feeding (2013).

2.2. Animals, experimental design, housing and dietary treatments (digestibility testing)

Assay I (digestibility testing) involved a total of 16 crossbred intact male pigs (Landrace × Large White) with 18.91 ± 1.36 kg of average initial body weight (AIBW) allocated in a randomized block design and divided into two experimental groups (reference diet and test diet), eight animals per group and one animal per experimental unit. The blocks were formed considering the initial body weight of the pigs.

The animals were individually housed in metabolism cages similar to those described by Pekas (1968), with a plastic screen attached to a square to collect feed leftovers and avoid faecal samples losses, a urine collecting hopper at the bottom of the cage and a faeces collection box at the back, equipped with a feeder-drinking in a partially controlled environment, where they remained for 12, 7 days for acclimatisation to cages and feed, and 5 days for collection of feces and urine. The average ambient temperature measured with the aid of a data logger (UNI-T UT 330B digital USB; Pequim, China) during the experimental period was 24.80 ± 4.15°C. The average relative humidity was 92.12 ± 16.63%.

The reference diet (RD) was composed of corn and soybean meal, formulated to meet the nutritional requirements of the animals in the starter phase according to the levels reported by Rostagno et al. (2017) (Table 1), and the test diet (TD) was the RD with a 20% replacement by GSM in 100% of the entire formulation.

2.3. Animals, experimental design, housing and dietary treatments (performance testing)

For the growth performance trial (assay II), plasma parameters and diarrhea incidence trial, a total of 128 crossbred intact male pigs (Landrace × Large White) with an AIBW of 14.47 ± 2.09 kg were used in a randomized block design, with four treatments repeated four times in two blocks of four animals per experimental unit (EU), totalling eight replications per treatment (four replications per block). The experimental plots were constituted in time, that is, two batches of piglets.

The piglets were identified with numbered ear tags and housed in suspended nursery stalls (1.50 m²), with polyethylene plastic flooring, equipped with pacifier type drinking fountains and feeders type gutter, and located in masonry shed with concrete flooring and ceramic roof tiles. Diets and water were provided ad libitum throughout the experimental period.

The ambient temperature (°C) and relative humidity (RH), during the experimental period were measured with the aid of a data logger (UNI-T UT 330B digital USB; Pequim, China) and controlled by opening or closing tilting windows and with the use of infrared incandescent lamps individual per stall. The average ambient temperature (°C) and average

| Ingredients         | Centesimal composition (kg/100 kg) |
|---------------------|------------------------------------|
| Ground corn         | 57.79                              |
| Soybean meal        | 33.90                              |
| Soybean oil         | 3.686                              |
| Monocalcium phosphate| 1.687                            |
| Calcium limestone   | 1.207                              |
| Common salt         | 0.457                              |
| Mineral-vitaminic premix | 0.500            |
| L-lysine HCL, 98%   | 0.416                              |
| DL-methionine, 99%  | 0.177                              |
| L-threonine, 96%    | 0.169                              |
| L-tryptophan, 99%   | 0.022                              |
| Total (%)           | 100                                |

Calculated composition (%): Crude protein 20.55; Metabolizable energy, kcal/kg 3350; Available phosphorus 0.450; Sodium 0.205; Digestible lysine 1.281; Digestible methionine + cysteine 0.730; Digestible threonine 0.833; Digestible tryptophan 0.243.

1Warranty levels/kg of product (1 g of product/kg of feed): folic acid (103.12 mg); pantothentic acid (2249.99 mg); biotin (16.88 mg); chlorohydroxyquinoline (15.00 g); copper sulphate (22.07 g); ethoxyquin (206.00 mg); iron sulphate (6733.40 mg); iodine (37.51 mg); lysine (123.76 g); manganese sulphate (1866.71 mg); methionine (110.25 g); niacin (4687.50 mg); selenium – sodium selenite (43.75 mg); threonine (46.64 mg); vit. A (1437.500.00 IU); vit. B1 (224.96 mg); vit. B2 (2537.50 mg); vit. B6 (457.50 mg); vit. B12 (625.000.00 IU); vit. E (4250.00 mg); vit. K3 (375.00 mg); zinc oxide (1000.00 mg).

2Nutritional composition analysed of reference diet and tested diet, respectively (%): crude protein, 20.73 and 18.00; organic matter, 84.23 and 85.38; dry matter, 89.56 and 89.65; neutral detergent fibre, 14.32 and 31.62; acid detergent fibre, 5.02 and 17.10; gross energy (kcal/kg), 4059 and 4186.
relative humidity of the shed were 24.41 ± 3.57°C and 96.13 ± 11.70%, respectively.

Treatments consisted of four increasing levels of GSM inclusion in the diet, being a reference diet (RD, 0%), RD 5%, RD 10% or RD 15% of GSM. The diets were formulated based on corn and soybean meal, in order to meet the nutritional requirements of piglets in the starter phase according to Rostagno et al. (2017) (Table 2).

The animals were weighed at the beginning and at the end of the experimental period with the aid of a digital scale (Rinnert digital scale, model BPW-5000; Braço do Trombudo, SC, Brazil). The amount of feed provided and its leftovers were also weighed at the end of the experimental period. These data were used to determine the growth performance variables: average daily feed intake (ADFI), average daily gain (ADG), final body weight (FBW) and feed conversion ratio (FCR).

### 2.4. Sample collection and preparation (digestibility testing)

In the digestibility trial, the diets provided and the urine and faeces collection were according to the procedures described by Sakamura and Rostagno (2016). During the collection period, feed supply was calculated based on the metabolic body weight (BW0.75) of each pig and on the average feed intake recorded during the acclimation period. The diets were provided at 08h00 and at 16h00.

During the collection period, 2% of ferric oxide (Fe2O3) was added to the feed to mark the beginning and end of faecal collection. The excreted faeces for each experimental unit were collected twice a day (morning and afternoon), weighed and labelled plastic bags, identified and stored in a freezer at −5°C. After the collection period, faecal samples were thawed, weighed (stainless steel digital scale, model UL50i; Pequim, China), homogenized and dried in a forced ventilation oven (Tecnal brand, SF-325 NM model; Piracicaba, SP, Brazil) at 55°C for a period of 72 h. After drying, samples were ground in a Wiley type grinder mill (Fortinox brand, Star FT 60 model; Piracicaba, SP, Brazil) and stored in polyethylene pots for laboratory analysis, which were performed in the Animal Nutrition laboratory, belonging in the UNIOESTE.

Urine was collected in plastic buckets containing 20 mL of 1:1 hydrochloric acid solution to avoid bacterial proliferation and nitrogen volatilization. After collection, the total volume of urine was measured and an aliquot (10% by total volume of urine) was conditioned daily in previously identified polyethylene terephthalate bottles, then stored in a freezer at −5°C. Subsequently, the samples were thawed, weighed, homogenized and aliquots taken (200 mL) for the GE determination in isoperibol calorimetric pump model 6200 (Parr Instrument Company; Moline, IL, USA).

Two feed samples (RD and TD), one sample of the test ingredient (GSM) with approximately 300 g, and the faecal samples were analysed at the Animal Nutrition Laboratory of UNIOESTE, following the methodologies described by AOAC (2005). The apparent digestibility coefficients of dry matter (ADCDM), organic matter (ADCOM), crude protein (ADCSCP), gross energy (ADCGE), neutral detergent fibre (ADCNDF), acid detergent fibre (ADCADF), and the coefficient of apparent metabolism of gross energy (AMCGE) were calculated according to the equations described by Matterson et al. (1965).

### 2.5. Blood sampling and analysis procedures (performance testing)

To evaluate the plasma concentrations of urea and glucose at the end of the nursery phase, the piglets were submitted to eight hours fasting prior to blood collection, then two animals were selected per EU, which corresponded to eight piglets per treatment in each block. Blood was collected (10 mL) via the cranial vena cava. Then, the samples were transferred to test tubes containing anticoagulant for urea (ethylenediaminetetraacetic acid – EDTA) and glucose (sodium fluoride). Subsequently, the blood was centrifuged (Centriflab digital centrifuge, Model 80-28, Labingá; Maringá, PR, Brazil) at 3000g for 15 min to obtain blood plasma. Plasma samples were transferred to duplicate 1.5 mL Eppendorf polyethylene tubes, identified and stored in a freezer at −5°C for further analyses. Plasma urea (enzymatic-colorimetric method) and glucose (enzymatic-colorimetric method) concentrations were verified using commercial kits (Urea-PP and Glucose-PP),

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Table 2. Centesimal and chemical composition of diets experimental containing increasing levels of guava seed meal inclusion in the growth performance testing (as-fed basis).

| Ingredients                        | 0     | 5     | 10    | 15    |
|------------------------------------|-------|-------|-------|-------|
| Ground corn                        | 60.01 | 56.56 | 53.19 | 49.43 |
| Soybean meal                       | 26.52 | 25.91 | 25.28 | 27.89 |
| Soybean oil                        | 2.32  | 1.25  | 0.26  | 0.00  |
| Guava seed meal                    | 0.00  | 5.00  | 10.00 | 15.00 |
| Fish meal, 54.6% CP                | 3.00  | 3.00  | 3.00  | 3.00  |
| Monodicalcium phosphate            | 1.23  | 1.24  | 1.26  | 1.28  |
| Calcium                            | 1.02  | 1.02  | 1.02  | 1.02  |
| Common salt                        | 0.393 | 0.396 | 0.398 | 0.401 |
| Micronized soybean 38% CP          | 4.00  | 4.00  | 4.00  | 4.00  |
| Mineral-vitamin premix             | 0.500 | 0.500 | 0.500 | 0.500 |
| L-lysine HCL, 98%                  | 0.343 | 0.365 | 0.388 | 0.410 |
| DL-methionine, 99%                 | 0.205 | 0.223 | 0.240 | 0.220 |
| L-threonine, 96%                   | 0.231 | 0.250 | 0.269 | 0.237 |
| L-tryptophan, 99%                  | 0.073 | 0.070 | 0.072 | 0.068 |
| Antimicrobial growth promoter      | 0.145 | 0.145 | 0.145 | 0.145 |
| Calculated composition (%)         | 0.145 | 0.145 | 0.145 | 0.145 |

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1 Warranty levels/kg of product (1 g of product/kg of feed): folic acid (103.12 mg); panthotenic acid (2249.99 mg); biotin (16.88 mg); chlorohydroxyquinoline (15.00 mg); copper sulphate (22.07 g); ethoxyquin (206.00 mg); iron sulphate (6733.40 mg); iodine (37.51 mg); lysine (123.76 mg); manganese sulphate (1866.71 mg); methionine (110.25 g); niacin (4687.50 mg); selenium – sodium selenite (43.75 mg); threonine (46.64 g); vit. A (1,437,500.00 IU); vit. B1 (224.96 mg); vit. B2 (2537.50 mg); vit. B6 (437.50 mg); vit. D3 (262,500.00 IU); vit. E (4250.00 IU); vit. K3 (375.00 mg); zinc oxide (1000.00 mg).

2 Colistin (0.085 g); amoxicillin (0.060 g).
respectively, and determined using a spectrophotometer (Bel SPECTRO S05, Biovera; Ramos, RJ, Brazil).

2.6. Diarrhea incidence (DI)

To evaluate the DI, visual faeces observations were daily recorded from the first day of the experimental period. A total of 544 observations (4 treatments × 4 replications × 2 blocks × 17 days) from 32 stalls (16 stalls × 2 blocks), containing four pigs were recorded. Records were performed at 17 times, expressed by the 17 days that represented the experimental period in each block. The variables analysed were average diarrhoea score (ADS) and diarrhea incidence (%). Scores from 0 to 3 were assigned for each stall: 0 = solid faeces, 1 = pasty faeces, 2 = liquid/pasty faeces and 3 = liquid faeces. Only the scores 2 and 3 indicated DI (Pérez-Calvo et al. 2019).

2.7. Calculations and statistical analysis

After the final adjustment of the analysis models of variance (ANOVA) and covariance (ANCOVA), the normality of the experimental errors and the homogeneity of the variances of the experimental errors between the treatments for the various characteristics were evaluated using the Shapiro–Wilk and Levene tests, respectively.

The ANCOVA was performed to verify the effects of GSM and AIBW levels on the characteristics. When the effect of AIBW was detected, the statistical model used was expressed by \( Y_{ijk} = m + T_i + b_j + \beta (X_{ijk} - \bar{X}) + \epsilon_{ijk} \). The effects of the factors included in the model are described by: \( Y_{ijk} = \text{average observation of the dependent variable in each plot, measured at the i-th GSM level, j-th block and k-th replication}; m = \text{overall average effect}; T_i = \text{GSM levels effect, for } i = (1, 2, 3 and 4); b_j = \text{blocks effect, for } j = (1 and 2); \beta = \text{Regression coefficient of Y on X}; X_{ijk} = \text{average observation of the covariate (AIBW) in each plot, measured at the i-th GSM level, j-th block and k-th replication}; \bar{X} = \text{overall average for the covariate X and } \epsilon_{ijk} = \text{random error of the plot associated with each observation } Y_{ijk} \).

After, for the characteristics that the effect \( P > 0.05 \) of AIBW was not detected, ANOVA was performed to verify the effects of the treatments, by adopting the statistical model described previously, without the use of covariates. For the characteristics that had an effect \( P < 0.05 \) of AIBW, the homogeneity test of the 1st-degree linear regression coefficients (betas) was carried out.

When the effect of treatments \( P < 0.05 \) on ANCOVA or ANOVA was found, the effects of GSM levels on the variables were estimated using linear regression models. Models were adjusted to the average data of the dependent variables, based on GSM values (0, 5, 10 and 15%). The selection of the predictive model that best fit the averages values of the variables was based on the significance of the parameters and on the value of the determination coefficient \( R^2 \).

Generalized linear models (GLM) with error structure and Poisson distribution (AFS – average faecal score) and normal distribution (ADI – average diarrhoea incidence), with logarithmic linkage functions \( g(\mu) = \ln(\mu) \) and identity \( g(\mu) = \mu \), respectively, were adjusted to test the effects of treatments.

The GLM used was represented by systematic portion \( \eta = g(\mu) = \mu + T_i + b_j \), where \( \mu \) is the effect of the overall average, \( T_i \) is the effect of GSM levels (\( i = 1, 2, 3 \) and 4) and \( b_j \) is the effect of the blocks (\( j = 1 \) and 2). The effect of quantitative treatments on the variables was assessed using Poisson (ADS) and logistic (DI) regression in the GLM. The parameters of the models were estimated using the maximum likelihood method, by maximizing the log-likelihood function, using generalized estimating equation by the Z statistic.

The significance level of 0.05 was adopted in all hypothesis tests. All statistical analyses were performed using the R Development Core Team (2013) and SAS University Edition (SAS Inst. Inc., Cary, NC, USA).

3. Results

3.1. Physicochemical-energetic composition, coefficients of apparent digestibility and coefficients of apparent metabolizability, values of nutrients and digestible energy

GSM can be an alternative dietary fibre in starter phase because it does not affect the calculated values for apparent digestibility coefficients, nutrients and digestible energy. Values higher were found for the amino acids considered conditionally essential (glutamine and arginine) (Table 3). The high GE value of the GSM reflected in an elevated AMCGE of the feed. This AMCGE results also reflected in greater DM and CP digestibility values (Table 4).

Table 3. Chemical and energetic composition of the guava seed meal (as-fed basis).

| Composition | GSM          |
|-------------|--------------|
| Dry matter, % | 89.91        |
| Gross energy, kcal/kg | 4610        |
| Crude protein, % | 10.06       |
| Lysine, %    | 0.13         |
| Threonine, % | 0.19         |
| Methionine, % | 0.03        |
| Tryptophan, % | 0.15        |
| Arginine, %  | 0.79         |
| Valine, %    | 0.27         |
| Isoleucine, % | 0.24        |
| Leucine, %   | 0.49         |
| Histidine, % | 0.15         |
| Phenylalanine, % | 0.28    |
| Tyrosine, %  | 0.29         |
| Alanine, %   | 0.26         |
| Proline, %   | 0.23         |
| Cystine, %   | 0.08         |
| Serine, %    | 0.29         |
| Histidine, % | 0.15         |
| Glutamic acid, % | 1.13   |
| Aspartic acid, % | 0.62    |
| Ash, %       | 3.31         |
| Organic matter, % | 96.78   |
| Ethereal extract, % | 1.69    |
| Neutral detergent fibre, % | 81.08   |
| Acid detergent fibre, % | 62.40   |
| Total carbohydrates, % | 84.94   |
| Non-fibrous carbohydrates, % | 3.86   |
| Starch, %    | 6.50         |
| Cellulose, % | 37.06        |
| Hemicellulose, % | 18.68   |
| Lignin, %    | 23.57        |
| Tannin, %    | 0.35         |

1Values are expressed based on natural matter.
Table 4. Apparent digestibility coefficients, coefficient of apparent metabolizability of gross energy, values of nutrients and digestible energy of the guava seed meal determined in the starter phase of piglets.

| Apparent digestibility coefficients, % | GSM<sup>†</sup> | ADCDM | ADCOM | ADCCP | ADCGE | AMCGE | ADCNDF | ADCADF | AMCGE |
|--------------------------------------|----------------|--------|--------|--------|--------|--------|---------|---------|--------|
| DM, %                                | 77.18          | 77.18  | 77.18  | 77.18  | 77.18  | 77.18  | 77.18   | 77.18   | 77.18  |
| OM, %                                | 76.79          | 76.79  | 76.79  | 76.79  | 76.79  | 76.79  | 76.79   | 76.79   | 76.79  |
| DP, %                                | 8.39           | 8.39   | 8.39   | 8.39   | 8.39   | 8.39   | 8.39    | 8.39    | 8.39   |
| NDF, %                               | 48.12          | 48.12  | 48.12  | 48.12  | 48.12  | 48.12  | 48.12   | 48.12   | 48.12  |
| ADF, %                               | 24.15          | 24.15  | 24.15  | 24.15  | 24.15  | 24.15  | 24.15   | 24.15   | 24.15  |
| DE, kcal/kg                          | 3275           | 3275   | 3275   | 3275   | 3275   | 3275   | 3275    | 3275    | 3275   |
| ME, kcal/kg                          | 3210           | 3210   | 3210   | 3210   | 3210   | 3210   | 3210    | 3210    | 3210   |
| ME:DE                                | 0.98           | 0.98   | 0.98   | 0.98   | 0.98   | 0.98   | 0.98    | 0.98    | 0.98   |

<sup>†</sup>ADCDCM = apparent digestibility coefficient of dry matter; ADCOM = apparent digestibility coefficient of organic matter; ADCCP = apparent digestibility coefficient of crude protein; ADCGE = apparent digestibility coefficient of gross energy; AMCGE = apparent metabolizability coefficient of gross energy; ADCNDF = apparent digestibility coefficient of neutral detergent fibre; ADCADF = apparent digestibility coefficient of acid detergent fibre.

3.2. Growth performance, plasma parameters and diarrhea incidence

No effects of the treatments on the FBW (P = 0.308), ADG (P = 0.280) and glucose concentration (P = 0.148) of the piglets were observed. However, there was effect of treatments on the ADFI (P = 0.002), FCR (P = 0.005) and urea concentration (P = 0.007) of piglets (Table 5 and Figures 1 and 2).

There was an effect of treatments on ADS (P = 0.017) and DI (P = 0.025) (Figure 3). From the obtained equation there was a logarithmic and a hyperbolic response (P < 0.05) of the ADFI (Figure 1), demonstrating that both equations can be estimated. However, the most reliable response is hyperbolic due to better data adequacy.

4. Discussion

4.1. Physicochemical-energetic composition, coefficients of apparent digestibility and coefficients of apparent metabolizability, values of nutrients and digestible energy

For our information there seem to be few reports on the use of GSM in starter piglet diets. The values regarding physicochemical-energetic composition of GSM were lower than those reported in a study with guava residue meal conducted by Silva et al. (2009). In contrast, GSM presented greater GE values in relation to the corn grain (4610 kcal/kg) evaluated by Rostagno et al. (2017). The percentage of DM (89.91%) of the GSM in our study was higher than the studied by Tardocchi et al. (2014) for guava residue meal (83.06%).

The essential amino acids values for GSM were lower when compared to the corn grain described by Rostagno et al. (2017). However, values higher than that of corn grain were found for the amino acids considered conditionally essential (glutamine and arginine) (Gomes and Stella 2018). According to Souza et al. (2011), fruits in general are not potential protein sources, however, this macronutrient is predominantly found in peels and seeds.

Regarding the constituents of the cell wall, the GSM due to the high contents of NDF has an insoluble fibre characteristic, which assigns as the main characteristic the low viscosity and retention of large amounts of water, interfering in the gastrointestinal tract and increasing intestinal motility, reducing the transit time and increasing evacuation frequency by providing the mass needed for peristaltic action (Roberto et al. 2015).

Most of the energy from GSM is in the cellulose form (37.06%), but the use by pigs is limited. In the digestive tract of pigs are present digestive enzymes that do not act effectively on cellulose and lignin. According to Kerr and Shurson (2013), the hemicellulose for the pigs is considered more digestible than cellulose, and that cellulose digestion can be impacted in addition to hemicellulose and the more soluble forms of fibre. Therefore, the susceptibility to hemicellulose in the breakdown of chemical bonds to gastric acidity is more ‘sensitive’, so that the products of this hydrolysis are exposed to digestion (Teixeira 1995).

The ADCDM values were higher than those reported by Carvalho et al. (2009), who evaluated the replacement of corn by increasing levels of ensiled and sticky coffee pulp (5; 10 and 15%) and obtained DCDM values of (62.64% and 59.91%). Corroborating these results, Silva et al. (2008) evaluated cassava root silage without inoculants and obtained a DCDM of 92.57%. The DM was lower compared to the study evaluating guava pulp (90.9%) for piglets in starter phase (Tardocchi et al. 2014). Researches show that the dietary fibre increase negatively affects the digestibility of dry and organic matter (Noblet and Perez 1993; Le Goff and Noblet 2001), diverging from the results obtained in the present study.

The ADCCP for GSM was similar to those found in the corn grain (85%), sorghum (85%) and lower than that of millet (91%), described by Rostagno et al. (2017). Trindade et al. (2004) analysed the residue of dehydrated fruit pulps and obtained lower values of ADCCP (77.55%). Fachinello et al. (2015) evaluated the passion fruit seed meal and found values for DDM (62.39%), DOM (59.62%), DE (3974 kcal/kg), ME (3583 kcal/kg), DP (8%), DNDF (17.32%) and ADCADF (25.04%) lower than those of the present study.

In studies similar to our study, Shi and Noblet (1993), Piva et al. (1996) and Awati et al. (2006) verified the effects of fermentable fibrous polysaccharide sources. The aforementioned authors showed that beet pulp, soybean hulls and barley hulls, respectively, can act by controlling excess of microbial fermentation and on the protein in the large intestine, reducing ammonia excretion in the nitrogen form, and intervening in the ADCCP improvement.

Due to the high NDF content present in the GSM, it is possible that the high nutrient intake by microorganisms occurred, overestimating the nutrient digestibility values. This fact was described by Potkins et al. (1991), who claimed that the insoluble fibre fraction is digested in the large intestine through its total or partial fermentation, serving as energy source for the
bacteria present in the colon and for consequent production of short chain fatty acids (SCFA).

In similar researches, conducted by Castro et al. (2017) and Leal (2018), who tested different levels of dehydrated cassava by-product and acerola industrial residue in piglet feeding, respectively. The authors reported an ADCGE of 73.74% to 84.99% and AMCGE of 71.80% to 84.67% for dehydrated cassava by-product, and an ADCGE of 28.21% and AMCGE of 27.84% for acerola industrial residue, finding a ME:DE ratio similar to obtained in the present study.

This ME:DE ratio may be associated with the quality of the protein present in GSM, in which low-quality protein or in excess, causes a decrease in ME because amino acids not used for protein synthesis are catabolized, with urea excretion. Moreover, greater the urea concentration promotes higher urine excretion, which reduces the ME. For the growing starter phases, the highest ME:DE ratio is due to the biochemical characteristics of the carbohydrates present in the feed, especially the presence of simple sugars (glucose and fructose), which favours the enzymatic action and digestive process of the piglet in the post-weaning period (Trindade et al. 2004).

For the best use of the GE present in feed ingredients, the fibre content, the processing method, the ingested amount of the ingredient and the factors related to the animal such as age and weight (Santos et al. 2016) should be considered. The high GE value of the GSM is reflected in an elevated

Table 5. Growth performance and blood parameters of piglets receiving diets with increasing levels of guava seed meal.

| Variable† | Increasing levels of GSM (%) | FBW*, kg | 5 | 10 | 15 | R² | CV³ (%) | P⁴ |
|-----------|-----------------------------|---------|---|----|----|-----|---------|-----|
| ADFI**, kg | 0.8343 | 0.8990 | 0.9319 | 0.9030 | - | 3.15 | 0.308 |
| ADG, kg | 0.5577 | 0.5891 | 0.5731 | 0.6027 | - | 7.91 | 0.280 |
| FCR**, F:G | 1.5005 | 1.5186 | 1.6216 | 1.4994 | - | 9.82 | 0.005 |
| Glucose*, mg/dL | 22.90 | 26.58 | 25.02 | 32.69 | 0.728 | 19.22 | 0.007 |
| Urea, mg/dL | 203.23 | 218.09 | 186.96 | 161.73 | - | 17.01 | 0.148 |

Figure 1. Regression models of average daily feed intake of piglets in the starter phase as a function of guava seed meal levels (%).
AMCGE of the feed, enabling the digestion process of other nutrients despite the high fibre content (Oliveira et al. 2006). This AMCGE results also reflected in greater DM and CP digestibility values.

As a characteristic of fibrous ingredients, ADCNDF and ADCADF were highest, which may be related to increased production of SCFA (not determined in the present study), raising the availability of fermentable substrate to microorganisms (Castro et al. 2005). Due to this, the acidic intestinal pH is maintained, inhibiting the proliferation of pathogenic bacteria and the formation of toxic substances (Goulart et al. 2016).

The chemical composition values are different due to several factors such as production site, fruit variety, proportion between pulp, seed and peel, maturation stage, handling, cultural treatments and technology level of the beneficiary units in the separation of the fruit portions. Considering the protein and energy levels found in the chemical composition of the GSM, it can be used in pigs feeding. Therefore, GSM suggests relevant nutritional values in diets for starter piglets.

4.2. Growth performance, plasma parameters and diarrhea incidence

It can be observed that the increase of GSM levels promoted a rise of the ADFI values and that the 10% GSM level provides greater ADFI for piglets in starter phase, which may be justified by the fact that insoluble fibre reduces the retention time of the feed in the digestive tract, thus, the ADFI increases to compensate the continuous emptying of the gastrointestinal tract (Wenk 2001; Montagne et al. 2003).

Budiño et al. (2015) evaluated diets for pigs in the starter phase, containing alfalfa hay and fructooligosaccharides, and verified similar results for ADFI. According to Souza da Silva et al. (2012) and Zhang et al. (2013), the higher fibre concentrations in pig feeding can significantly reduce voluntary intake due to the filling effect on the gastrointestinal tract (GIT) of the animal, causing satiety, which may explain the lower ADFI for the 15% GSM inclusion level (Table 5).

Considering that animal body weight gain may be directly influenced by feed intake and nutrient utilization, it is speculated that the increase of dietary fibre associated with a greater inclusion of GSM could impair the results of ADG and FCR. Our findings corroborate those of Fachinello et al. (2015), who did not observe differences in the growth performance variables of pigs in starter phase. Pigs in finishing phase when fed high levels of dietary fibre are able to maintain ADG in adequate rates due to their ability to increase feed intake as an attempt to maintain a stable level of digestible energy ingested (Bindelle et al. 2008).

Studies using dried fruit pulp residue in replacement of corn in the diet did not verify growth performance impairment with the inclusion of dietary fibres for ADFI (Trindade et al. 2004). Farias et al. (2008) tested cashew tree pseudofruit in diets for pigs in growing phase and reported that the by-product can
be included up to 20% in the diet without affecting growth performance. Pascoal et al. (2012) assessed soybean hulls, citrus pulp and purified cellulose in piglet diets and concluded that the use of these ingredients did not affect the productive performance of the animals.

There is some discrepancy of results in relation to the growth performance of piglets fed with dietary fibre sources and it may be due to the chemical and physical characteristics of each fibre source and their lignification degrees, as well as the amount included in the feed (Budiño et al. 2015).

Soluble fibre has high water absorption capacity that increases the digesta viscosity, so the food bolus remains longer in the GIT, reducing contact between the digestive enzymes and substrate, consequently there is a reduction in the nutrient digestibility and voluntary feed intake. Insoluble fibres are responsible for reducing the digesta retention time and nutrient absorption, increasing water retention (Sakomura et al. 2014), which is in accordance with the fibre characteristics of GSM. The ability of pigs to use diets containing dietary fibre increases considerably as the animal develops due to the larger size of the GIT, especially large intestine, and the greater microbial population (cellulolytic bacteria) found in the cecum (Pascoal et al. 2012).

According to Frank et al. (2005), fibre can reduce the digestibility of other dietary nutrients. Although the inclusion of GSM increased the level of insoluble fibre in the feed, the performance of the animals was not impaired; therefore, its use in the piglets feeding in starter phase can be up to 15% of inclusion without compromising the growth performance.

The reference concentrations of urea and glucose established for pigs are 15–45 mg/dL and 60–110 mg/dL, respectively (Genova et al. 2019). It can be observed that the urea values are close to the established range, but for the glucose concentration the levels were higher than those in the range, even with diets formulated to meet the animal phase requirements. The estimated urea average increase may be related to a greater feed intake, consequently protein intake is increased. Therefore, the urea concentration interferes with the animal’s nutritional condition, as well as in response to the quality of the protein provided (Wei and Zimmerman 2003).

Glucose metabolism may be influenced by dietary characteristics, i.e. grain-rich diets tend to have better non-structural carbohydrate digestion in the small intestine and higher blood glucose supply, while fibre-rich diets promote higher conversion of structural carbohydrates in SCFA in the cecum and colon (López and Stumpf 2000). In recent researches by Castro et al. (2017) and Leal (2018) using alternative ingredients similar to the present study in piglet feeding also observed no effect for the variable glucose.

Beneficial effects of the use of dietary fibres for piglets have been reported in other studies (Lindberg 2014; Jha et al. 2019), confirming our findings on the inclusion of GSM in starter piglet diets. Mateos et al. (2006) and Hanczakowska et al. (2007) reported a reduction in the diarrhea incidence in piglets fed diets containing 2% oat hulls and purified cellulose,
respectively. The fact that piglets showed a reduction in the diarrhoea incidence is supported by the various positive effects that the inclusion of fibre promotes in the post-weaning period, through a benefit in the commensal microbiota in the large intestine and due to the end products of fermentation.

5. Conclusion

Based on the results, GSM can be an alternative source of dietary fibre in the piglets feeding in starter phase. GSM replacement level does not affect the calculated values for the ADC, digestible nutrients and energy of diets.

Increased dietary GSM levels promote greater insoluble fibre content and higher ADFI by up to 10% inclusion. Pigs fed with the inclusion of 15% GSM showed greater plasma urea concentration. There are no significant changes in pig energy metabolism with increasing dietary GSM levels on the plasma glucose concentration. The GSM 15% inclusion in starter piglet diets promotes an improvement in ADS and DI. Moreover, its addition in pigs feeding in starter phase promotes in the post-weaning period, carcass, and blood characteristics in stater pigs. Trop Anim Health Prod. 47(7):1397–1407. doi: 10.11120/tahp.2015b.015–08775.

Farias LA, Lopes JB, Figueiredo AD, Albuquerque DM, Neto AAA, Ramos LSN. 2008. Cashew pummels oil (Anacardium Occidentale L.) for growing pig: nutrient metabolism and performance. Ciênc Anim Brasil. 9(1):100–109. doi: 10.5216/cab.v9i1.3673.

Frank N, Andrews FM, Elliott SB, Lew J, Boston RC. 2005. Effects of rice bran oil on plasma lipid concentrations, lipoprotein composition, and glucose dynamics in mares. J Anim Sci. 83(11):2509–2518. doi:10.2527/2005.83112509x.

Furlan AC, Mantovani C, Murakami AE, Moreira I, Scapinello C, Martins EN. 2001. Use of sunflower meal in broiler chicks feeding. Rev Bras de Zootec. 30(1):158–164. doi:10.5216/cab.v9i1.3673.

Genova JL, Carvalho PLDO, Oliveira NTED, Oliveira ADC, Gois FD, Castro DEDS, Souza FNC, Trautenmuller H, Santos LBDDAD, Leal IF. 2019. Partial replacement of soybean meal with different protein sources in piglet feed during the nursery phase. Asian-Australas J Anim Sci. 32(11):1725–1733. doi:10.5713/ajas.17.07535.

Georganas A, Giamouri E, Pappas AC, Papadomichelakis G, Galliou F, Manios T, Zervas G. 2020. Bioactive compounds in food waste: a review on the transformation of food waste to animal feed. Foods. 9(3):291. doi:10.3390/foods9030291.

Gomes KB, Stella AL. 2018. Arginine nutrition in neonatal pigs. Rev Eletr Nutrimente. 15(1):8081–8080.

Goulart FR, Adorim TJ, Mombach PI, Silva LP. 2016. Importance of dietary fiber in non-ruminant animal nutrition. Rev Ciênc Inova. 1(1):141–154. doi:10.26669/2448-4091104.

Hanczewska E, Wytkiewicz M, Szweczyk A. 2007. Effect of dietary nettle extract on pig meat quality. Medy Weter. 63(5):525–527. doi:10.17221/49/2016-CJAS.

Jarrett S, Ashworth C. 2018. The role of dietary fibre in pig production, with a particular emphasis on reproduction. J Anim Sci Biotechnol. 9:1–11. doi:10.1186/s40104-018-0270-0.

Jha R, Fohuse JM, Tiware UP, Li L, Willing BP. 2019. Dietary fiber and intestinal health of monogastric animals. Front Vet Sci. 6:1–1. doi:10.3389/fvets.2019.00048.

Kerr BJ, Shurson GC. 2013. Strategies to improve fiber utilization in swine. J Anim Sci Biotechnol. 4(1):11. doi:10.1186/2049-1891-4-11.

Leal IF. 2018. Dry residue of acerola industrialization in swines feeding in the starter phase [Master’s thesis]. IN: State University of Western Paraná. http://tede.unioeste.br/handle/tede/4025.

Le Goff G, Noblet J. 2001. Comparative total tract digestibility of dietary energy and nutrients in growing pigs and adult sows. Anim Sci J. 79(9):2418–2427. doi:10.2527/2001.7992418x.

Lindberg JE. 2014. Fiber effects in nutrition and gut health in pigs. J Anim Sci Biotechnol. 5(1):15. doi:10.1186/2049-1891-5-15.

López J, Stumpf JRW. 2000. Influence of sorghum grain as a source of starch in sheep fed hay. Plasma Parameters Rev Bras Zootec. 29(4):1183–1190. doi:10.17221/15065-2000.0400032.

Lousada Júnior E, Costa JMC, Neiva JNM. 2006. Physical-chemical characterization of tropical fruit by-products for use in animal feed. Rev Ciênc Agron. 37(1):70–76.

Mateos GG, Martin F, Latorre MA, Vicente B. 2006. Inclusion of oat hulls in diets for young pigs based on cooked maize or cooked rice. Anim Sci J. 82(2):57–63. doi:10.1016/j.anifeedsci.2006.07.006.

Matterson LD, Potter LM, Stutz MW, Singsen EP. 1965. The metabolizable energy offered ingredients for chickens. Res Rep Connect Agric Exp Stn. 7(11):1–14.

Montagne L, Pluske JR, Hampson DJ. 2003. A review of interactions between dietary fibre and the intestinal mucosa, and their consequences on digestive health in young non-ruminant animals. Anim Feed Sci Technol. 108(1–4):95–117. doi:10.1016/S0377-8401(03)00163-9.

Navarro D, Bruinex E, de Jong L, Stein HH. 2018. The contribution of digestible and metabolizable energy from high-fiber dietary ingredients is not

References

Association of Official Analytical Chemists – AOAC. 2005. Official methods of association, 18th ed. Arlington, VA: The Association of Official Analytical Chemists.

Awati A, Williams BA, Bosch MW, Gerrits WJ, Verstegen MV. 2006. Effects of dietary nettle meal in broiler chicks feeding. Rev Bras de Zootec. 30(1):158–164. doi:10.5216/cab.v9i1.3673.
affected by inclusion rate in mixed diets fed to growing pigs. J Anim Sci. 96:1860–1868. doi:10.1093/jas/sky090.

Noblet J, Perez JM. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. Anim Sci J. 71(12):3389–3398. doi:10.2527/1993.71123389x.

Oliveira RAG, Lima EQ, Vieira WL, Freire KRL, Trajano VN, Lima IO, Souza EL, Toledo MS, Raimundo NFS. 2006. Study of the interference of essential oils on the activity of some antibiotic used clinically. Rev Bras Farmacogn. 16(1):77–82. doi:10.1590/S0102-695X2006000100014.

Pascoal LAF, Thomaz MC, Watanabe PH, Ruiz U, Ezequiel JMB, Amorim AB, Daniel E, Masson GCJ. 2012. Fiber sources in diets for newly weaned piglets. Rev Bras Zootec. 41(3):636–642. doi:10.1590/S1516-35982012000300024.

Pekas JC. 1968. Versatile swine laboratory apparatus for physiologic and metabolic studies. Anim Sci J. 2(5):1303–1306. doi:10.2527/1968.2751303x.

Pérez-Calvo E, Wicaksono AN, Canet E, Daulton E, Ens W, Hoeller U, Teixeira EW. 1995. Use of ruminant nutrition, 1st ed. Jaboticabal, SP: Funep.

Pivá A, Panciroli A, Meola E, Formigoni A. 1996. Lactitol enhances short- chain fatty acid and gas production by swine cecal microflora to a greater extent when fermenting low rather than high fiber diets. J Nutr. 126(1):280–289. doi:10.1093/jn/126.1.280.

Potkin ZV, Lawrence TLJ, Thominson JR. 1991. Effects of structural and non-structural polysaccharides in the diet of the growing pig on gastric emptying rate and rate of passage of digesta to the terminal ileum and through the total gastrointestinal tract. Br J Nutr. 65(3):391–413. doi:10.1079/bjn19910100.

R Development Core Team. 2013. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. ISBN 3-900051-07-0.

Roberto BS, Silva LP, Macagnan FT, Bizzani M, Bender ABB. 2015. Nutritional quality and acceptability of the guava peel and seed-added cereal bars. R Inst Adolfo Lutz. 74(1):39–48.

Rostagno HS, Albino LFT, Gomes PC, Lopes DC, Barreto SLT. 2017. Brazilian tables for ruminant nutrition, 1st ed. Jaboticabal, SP: Funep.

Sakomura NK, Rostagno HS. 2016. Monogastric nutrition research methods, 2nd ed. Jaboticabal, SP: Funep.

Sakomura NK, Silva JHV, Costa FG, Fernandes JBK, Hauschild L. 2014. Non-structural polysaccharides in the diet of the growing pig on growth rate of 348 g/d. J Anim Sci. 81(7):1772–1780. doi:10.2527/2003.8171772x.

Sakomura NK, Silva JHV, Freire KRL, Trajano VN, Lima IO, Souza EL, Santos SL, Mascarhenas GA, Oliveira FH. 2016. Digestive physiology and nutrition post weaning piglets. Rev Elet Nutrit. 13(1):4570–4584.

Shi XS, Noblet J. 1993. Contribution of the hindgut to digestion of diets in growing pigs and adult sows: effect of diet composition. Livest Prod Sci. 34(3-4):237–252. doi:10.1016/0301-6226(93)90110-4.

Silva MAA, Furlan AC, Moreira I, Paiano D, Scherer C, Martins EN. 2008. Nutritional evaluation of cassava root silage with or without whole soybean for nursery piglets. Rev Bras Zootec. 37(8):1441–1449. doi:10.1590/S1516-35982008000800015.

Silva EP, Rabello CBV, Júnior WMD, Moreira W, Loureiro RVS, Guimarães AAS, Lima MB, Arruda EMF, Barbosa-Lima R. 2009. Economic evaluation of tomato and guava residues inclusion in laying hens ration. Rev Bras Saúde Prod. 40(4):774–785.

Sniffen CJ, O’connor JD, Van Soest PJ, Fox DG, Russel JB. 1992. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. J Anim Sci. 70(10):3562–3577. doi:10.2527/1992.70113562x.

Souza MSB, Vieira LM, Silva MJM, Lima A. 2011. Caracterização nutricional e compostos antioxidantes em resíduos de polpas de frutas tropicais. Ciência Agrotec. 35(3):554–559.

Souza da Silva C, van den Borne JJ, Gerrits WJ, Kemp B, Bolhuis JE. 2012. Effects of dietary fibers with different physicochemical properties on feeding motivation in adult female pigs. Physiol Behav. 107(2):218–230. doi:10.1016/j.physbeh.2012.07.001.

Tardocchi CFT, Soares RTRN, Bonaparte TP, Cabral NO. 2014. Digestibility of agro industrial residues for piglets in initial phase. Revista Elet Nutrit. 11(6):3770–3780.

Teixeira EW. 1995. Use of fibrous feed by pigs. Rev Bras Zootec. 33(1):19–27.

Trindade NMA, Petelinchar IM, Berto DA, Moreira JA, Vitti DMS. 2004. Powdered fruits pulp residue in the piglets feeding in the nursery phase. Rev Bras Zootec. 33(5):1254–1262. doi:10.1590/S1516-35982004000500018.

Wei R, Zimmerman DR. 2003. An evaluation of the NRC (1998) growth model in estimating lysine requirements of barrows with a lean growth rate of 348 g/d. J Anim Sci. 81(7):1772–1780. doi:10.2527/2003.8171772x.

Wenk C. 2001. The role of dietary fiber in the digestive physiology of the pig. Anim Feed Sci Technol. 90(1-2):21–33. doi:10.1016/S0377-8401(01)00194-8.

Zhang W, Li D, Liu L, Zang J, Duan Q, Yang W, Zhang L. 2013. The effects of dietary fiber level on nutrient digestibility in growing pigs. J Anim Sci and Biotechno. 4(1):1–17. doi:10.1186/2049-1891-4-17.

Ziemer CJ, Kerr BJ, Weber TE, Arcidiacono S, Morrison M, Ragauskas A. 2012. Effects of feeding fiber-fermenting bacteria to pigs on nutrient digestion, fecal output, and plasma energy metabolites. J Anim Sci. 90(11):4020–4027. doi:10.2527/jas.2012-5193.