Energy content, nutrient digestibility coefficient, growth performance and serum parameters of pigs fed diets containing tomato pomace

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ABSTRACT

This study designed was to evaluate energy content and apparent total tract digestibility (ATTD) of nutrients in tomato pomace (TP), and to determine the effects of TP on the performance of growing pigs. In Exp. 1, 12 barrows were allocated to 2 treatments, a basal diet or a diet containing 194.6 g/kg TP. Exp. 2, growing pigs (n = 180) were allocated to 5 treatments: T1 was a basal diet. T2 and T3 were diets containing 50 or 100 g/kg TP, respectively. T4 and T5 were based on T2 or T3 except that soybean oil (SBO) was added. Soybean oil was added such that digestible energy content was equivalent to basal diet. In Exp. 1, the DE and ME content of TP were 7.01 and 6.59 MJ/kg, respectively. The ATTD of DM, CP, GE, OM and NDF were 0.45, 0.54, 0.35, 0.46 and 0.39, respectively. In Exp. 2, TP addition linearly increased (P < .05) G:F and decreased (P < .05) ADG, ATTD of DM, EE, NDF, GE and OM. In 50 g/kg TP diet, SBO addition increased (P < .05) ATTD of DM, EE, NDF, GE and OM. Optimal supplementation of TP in diets is 50 g/kg for growing pigs, but increasing dietary energy density can largely eliminate the negative effects of fibre in TP.

Abbreviations: ADFI: average daily feed intake; ADG: average daily gain; ALB: albumin; ALT: glutamic-pyruvic transaminase; AST: glutamic oxalacetic transaminase; ATTD: apparent total tract digestibility; BW: body weight; CLB: globulin; CREA: creatinine; G:F: gain:feed ratio; GLU: glucose; GSH-Px: glutathione peroxidase; HDL-C: high-density cholesterol; MDA: malondialdehyde; P: total phosphorus; SBO: soybean oil; SOD: superoxide dismutase; SUN: serum urea nitrogen; T-AOC: total antioxidant capacity; TC: total cholesterol; TG: total triglyceride; TP: tomato pomace

1. Introduction

The by-product from the processing of tomatoes into sauce, puree, paste and juice is called tomato pomace (TP) and it consists of peels and seeds as well as small amounts of pulp (Shao et al. 2014). Pomace represents about 2–5% of initial tomato weight (Knoblich et al. 2005; Ventura et al. 2009) and the seeds make up nearly 60% of the dry matter of the pomace (Del Valle et al. 2006; Ruiz Celma et al. 2009).

Processing tomatoes is an important industry with production of 38.1 Mt worldwide, 16.0 Mt in the Mediterranean area, and 10.3 Mt in the EU. Of the total production, 71% came from California, Italy, China, Spain and Turkey (World Processing Tomato Council, 2016). The TP is described as potentially useful non-conventional livestock feed (Wadhwa and Bakshi 2013; Wadhwa et al. 2015). Previous research based on pigs have been evaluated using tomato pomace as replacements for other ingredients to reduce feed cost without adverse impact on growth performance (Caluya et al. 2000; Cilev et al. 2007), and dietary inclusion of tomato pomace improves meat oxidative stability in pigs (Correia et al. 2017). However, TP is limited in energy due to the high fibre content. The objective of this study was to evaluate the digestible and metabolizable energy content, total tract nutrient digestibility of TP and to determine the effects of dietary TP inclusion on growing pig performance.

2. Materials and methods

All procedures used in these experiments were approved by the Institutional Animal Care and Use Committee of China Agricultural University (Beijing, P. R. China).

Exp. 1 was conducted at the Metabolism Laboratory of the Ministry of Agriculture Feed Industry Centre (China Agricultural University, Beijing, P. R. China). Exp. 2 was conducted at the Swine Nutrition Research Center of the National Feed Engineering Technology Research Center (Chengde, P. R. China) for Exp. 2.

Tomato pomace, mean particle size of 1000 μm, was purchased from Chenguang Biotech Group Co., Ltd (Handan, P.R. China). Corn and soybean were ground in hammer mill using a 2-mm screen. The analysed chemical composition of TP was shown in Table 1.

All diets in these experiments were provided in mash form, and the experimental pigs (Duroc × Landrace × Yorkshire) were supplied by the Swine Nutrition Research Centre of the National Feed Engineering Technology Research Centre.
2.1. Animals, diets and experimental designs

Exp. 1 was conducted to evaluate the digestible energy (DE), metabolizable energy (ME) content and apparent total tract digestibility (ATTD) of nutrients in TP. Twelve barrows with an initial average body weight (BW) of 50.3 ± 1.1 kg were housed individually in stainless steel metabolism crates (1.4 × 0.7 × 0.6 m³) and randomly allocated to one of two treatments. The basal diet contained 973.0 g/kg corn and soybean meal, and the treatment diet was formulated to contain 194.6 g/kg TP which replaced corn and soybean meal in the basal diet (Table 2). All pigs were fed at 4% of their initial BW, which were determined one day before the trial. Daily feed allotment was divided into two equal portions which were fed at 08:30 and 15:30 h. All pigs were allowed ad libitum access to water through a nipple waterer located at the front of the crate. Room temperature was maintained at 20 ± 1°C and the trial lasted for 12 days.

In Exp. 2, 180 crossbred barrows and gilts with an average BW of 52.6 ± 2.5 kg were assigned to 5 treatments with 6 replicates (3 barrows and 3 gilts per pen) according to sex and BW in a randomized complete block design. Pigs were housed in partially steel-slatted and concrete-floored pens (2.6 × 1.8 m). Each pen was equipped with a stainless steel self-feeder and a nipple drinker. All pigs had free access to water and feed. The temperature of the barn was set at 25 ± 2°C. Ingredient composition and nutrient concentration of diets used in Exp. 2 are presented in Table 3. Treatment 1 was a corn-soybean meal basal diet which met the DE requirement for growing pigs recommended by NRC (2012). Treatments 2 and 3 were diets containing 50 or 100 g/kg TP respectively, which replaced corn and soybean meal in the basal diet. Treatments 4 and 5 were based on treatments 2 and 3 with soybean oil (SBO) added to increase the DE content equivalent to that in treatment 1. All diets were formulated to meet amino acids, vitamin, and mineral requirements for growing pigs according to NRC (2012) requirements. The DE content of TP determined in Exp. 1 was used in diet formulations and standardized ileal digestibility (SID) of amino acids for all relevant ingredients from NRC (2012). The digestible energy content of corn and soybean meal was calculated in accordance with prediction equations that were developed in our previous studies.

DE of corn: \( \text{[kcal/kg DM]} = 1062.68 + 49.72 \times \text{EE} \% \) – 24.89 \( \times \text{NDF} \% \) + 0.54 \( \times \text{GE}[\text{MJ/kg DM}] + 9.11 \times \text{Starch} \% \) (Li et al. 2014).

DE of soybean meal: \( \text{[MJ/kg DM]} = 38.44 - 0.43 \times \text{CF} \% - 0.98 \times \text{GE}[\text{MJ/kg DM}] + 0.11 \times \text{ADF} \% \) (Li et al. 2016).

Pigs were weighed at the beginning and end of the trial. The amount of feed offered to each pen was recorded, and at the end of the experiment, the total amount of feed left in the feeder was weighed and used to calculate feed disappearance. The average daily gain (ADG), average daily feed intake (ADFI), and gain:feed ratio (G:F) were calculated. Acid-insoluble ash (AIA) in feed and faeces was used as an endogenous indicator to calculate nutrient digestibility coefficients.

### Table 2. Composition of experimental diets and nutrient content in Exp. 1 (g/kg, as-fed basis).

| Item                        | Basal diet | Tomato pomace diet |
|-----------------------------|------------|---------------------|
| **Ingredients**             |            |                     |
| Corn                        | 784.8      | 627.8               |
| Soybean meal                | 188.2      | 150.6               |
| Tomato pomace               | 0.0        | 194.6               |
| Dicalcium phosphate         | 11.5       | 11.5                |
| Limestone                   | 7.5        | 7.5                 |
| Sodium chloride             | 3.0        | 3.0                 |
| Vitamin-mineral premix *    | 5.0        | 5.0                 |
| **Chemical composition**    |            |                     |
| Dry matter                  | 854.0      | 865.8               |
| Crude protein               | 141.3      | 143.7               |
| Aerator extract             | 19.0       | 22.7                |
| Neutral detergent fibre     | 154.5      | 214.5               |
| Acid detergent fibre        | 37.3       | 130.7               |
| Calcium                     | 6.1        | 6.3                 |
| Total phosphorus            | 4.8        | 4.7                 |
| Gross energy (MJ/kg)        | 15.8       | 16.6                |
| Organic matter              | 814.7      | 821.8               |

*Vitamin and mineral premix provided the following per kilogram of feed: Vitamin A, 5,512 IU; vitamin D₃, 2200 IU; vitamin E, 30 IU; vitamin K₃, 2.2 mg; vitamin B₁₂, 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 mg; Mn, 40 mg (MnO); Fe, 75 mg (FeSO₄·H₂O).
2.2. Sample collection

In Exp. 1, after a 7-d-adaptation period, a 5-d-total collection of faeces and urine was conducted. Feed refusals and spillage were collected, dried, and weighed for calculation of feed intake. Faeces were collected as they appeared in the metabolism crates and stored at −20°C for analysis. Urine was collected in a bucket containing 10 mL of 6 N HCl for every 1000 mL of urine to avoid loss of nitrogen. Total urine volume was measured daily, and a 10% aliquot of urine was filtered through gauze and pooled per pig and stored at −20°C. At the end of the animal trial, the sampled faeces and urine were pooled for each pig and subsamples were retained for chemical analysis. Subsamples of faeces were dried for 72 h at 65°C and ground through a 1-mm screen.

In Exp. 2, faecal samples were collected from each pig by rectal palpation on day 27 and 28 mixed within pig and dried as in Exp. 1. On day 29 after pigs were fasted for 12 h, one pig/per pen close to the average group BW was selected to collect a blood sample via jugular vein puncture into vacuum container tubes (Becton Dickinson Vacutainer Systems, Franklin Lakes, NJ, USA). Blood samples were allowed to clot at room temperature for 20 min and centrifuged at 3000×g at 4°C for 10 min. Serum was then removed and stored at −20°C until laboratory analysis.

2.3. Chemical analysis and calculation

All samples were ground to pass through a 1-mm screen before analysis and duplicate proximate analyses were performed. Samples of TP, diets, and faeces in the two experiments were analysed for dry matter (DM; AOAC 2007 method 930.15), crude protein (CP; AOAC 2007 method 984.13), aether extract (EE; AOAC 2000 method 920.39), ash (AOAC 2007 method 942.05), calcium (Ca; AOAC 2007 method 927.02) and total phosphorus (P; AOAC 2007 method 984.27). Organic matter (OM) was calculated as 100 minus the content of ash and water. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined using fibre filter bags and fibre analyzer equipment (Fibre Analyser, Ankom Technology, Macedon, NY) following an adaptation of the procedure described by Van Soest et al. (1991). The concentration of NDF was analysed using heat stable α-amylase and sodium sulphite without correction for insoluble ash (inclusive of residual ash). The ADF fraction was analysed in a separate sample (inclusive of residual ash). Total dietary fibre (TDF) and insoluble dietary fibre (IDF) in the ingredients and diets were analysed by using a combination of enzymatic and gravimetric procedures (Prosky et al. 1992). Dietary fibre values (IDF and TDF) were calculated as the weight of residue minus the weight of protein and ash. The concentration of soluble dietary fibre (SDF) in the ingredients and diets were calculated as the difference between TDF and IDF. Samples of TP, diets, faeces, and urine were analysed for gross energy (GE) with an isoperibol oxygen bomb calorimeter (Parr 6400 Calorimeter, Moline, IL). The diets and faeces in Exp. 2 were analysed for AIA by the methods described by McCarthy et al. (1974).

Levels of serum glutathione peroxidase (GSH-Px), malondialdehyde (MDA), superoxide dismutase (SOD) and total antioxidant capacity (T-AOC) were determined by commercially available kits (Jiancheng Biochemical Reagent Co., Nanjing, China) according to the manufacturer’s instructions. The concentrations of albumin (ALB), globulin (GLB), total protein (TP), high-density cholesterol (HDL-C), total cholesterol (TC), glutamic-pyruvic transaminase (ALT), glutamic oxaloacetic transaminase (AST), creatinine (CREA), serum urea nitrogen (SUN), glucose (GLU) and total triglyceride (TG) in serum were measured by corresponding kits (BioSino Biotechnology and Science Inc., Beijing, China) with an automatic biochemical analyzer (Hitachi 7160, Hitachi High-Technologies Corporation, Japan).

In Exp. 1, DE and ME content of the TP were calculated using the difference method according to Adeola et al. (2001). The ATTD of nutrients in diets was determined by the following equation (Kong and Adeola 2014):

\[ D_i = \frac{D_{bd} - [D_{bd} \times (1 - P_i)]}{P_i} \]

In this equation, \( D_{bd} \), \( D_{td} \) and \( D_a \) represent the digestibility (%) of the component in the basal diet, test diet, and test ingredient (TP), respectively, and \( P_i \) was the proportional contribution of the component by the test ingredient to the test diet, respectively. Digestibility coefficients were then determined by dividing grams of component digested by the grams of component consumed.

In Exp. 2, the ATTD of nutrients were calculated as follows (Kong and Adeola 2014):

\[ \text{Digestibility} \% = 100 - \left[ \frac{\text{CI}_{\text{input}} \times \text{CC}_{\text{output}}}{\text{CI}_{\text{output}} \times \text{CC}_{\text{input}}} \right] \times 100 \]

In this equation, \( \text{CI}_{\text{input}} \) and \( \text{CI}_{\text{output}} \) are the concentration of index compound (AIA) in feed and faeces, respectively; \( \text{CC}_{\text{input}} \) and \( \text{CC}_{\text{output}} \) are the concentration of component in feed and faeces, respectively. Digestibility coefficients were then determined by dividing grams of component digested by the grams of component consumed.

2.4. Statistical analysis

Data were checked for normality and outliers were detected using the UNIVARIATE procedure of SAS (SAS Institute, Cary, NC). No outliers were identified. In Exp. 1, data were analysed using the PROC GLM procedure of SAS (SAS Institute, Cary, NC). Pig was treated as the experimental unit. Treatment means were calculated using the MEANS statement and statistical differences among the treatments were separated by student’s t-test. In Exp. 2, pen was treated as the experimental unit and two methods were used for data analysis. Data were analysed using the PROC GLM procedure of SAS (SAS Institute, Cary, NC). Orthogonal contrast was used to determine the effect of 50 g/kg TP (−SBO) vs. 50 g/kg TP (+SBO), 100 g/kg TP (−SBO) vs. 100 g/kg TP (+SBO). An unprotected F-test was completed for the preplanned comparisons where the model was not significant. Polynomial contrasts were conducted to determine linear and quadratic effects of TP supplementation without additional SBO. Significant differences were declared at \( P < .05 \). Differences at \( .05 \leq P < .10 \) were considered a trend toward significance.
3. Results

3.1. Nutrient concentration, digestibility, digestible and metabolizable energy content in tomato pomace

There was no significant difference in the GE intake between pigs fed the basal diet or TP diet (Table 4). Pigs fed the TP diet had higher (P < .01) dry faeces output, GE in dry faeces, and faecal GE output, but decreased (P < .05) urine output, and exhibited a trend (P = .088) for increase GE in urine compared to the basal diet group. As a consequence, values for DE, ME, and DE/GE and ME/GE ratio were less (P < .05) in the TP diet; similarly, ATTD of DM, CP, EE, NDF, ADF, Ash, GE, and OM were lower (P < .01) in the TP diet (Table 5). The DE and ME content of TP were 7.01 and 6.59 MJ/kg (as-fed basis), respectively, and the ME/DE ratio was 0.94.

3.2. Effects of increasing energy density in tomato pomace on growth performance and total tract nutrient digestibility for growing pigs

There was no effect of tomato pomace inclusion, with or without added SBO, on final BW and ADFI (Table 5). Daily gain, G:F, and ATTD of DM, ADF and OM decreased linearly (P < .05) with increasing TP inclusion with no effect on CP digestibility. Digestibility of EE tended to linearly decrease (0.05 < P < .1) with increasing TP inclusion. The lack of difference in the GE intake between the treatments when diet contained 50 or 100 g/kg TP.

Table 4. Energy content and nutrient digestibility coefficients in tomato pomace and energy utilization variables in pigs provided diet containing tomato pomace (Exp. 1, as-fed basis).a

| Item                              | Basal diet | Tomato pomace diet | SEM   | P-value | Tomato pomaceb |
|-----------------------------------|------------|--------------------|-------|---------|----------------|
| Digestible energy, MJ/kg          | 13.89a     | 12.49b             | 0.07  | <.001   | 7.01           |
| Metabolizable energy, MJ/kg       | 13.77a     | 12.54b             | 0.02  | <.001   | 6.59           |
| Metabolizable energy/Digestible   | 0.99       | 0.99               | 0.18  | .309    | 0.94           |
| energy                            |            |                    |       |         |                |
| Digestible energy/Gross energy    | 0.72a      | 0.64b              | 0.34  | <.001   | 0.35           |
| Metabolizable energy/Gross energy | 0.71a      | 0.64b              | 0.37  | <.001   | 0.33           |
| Digestibility coefficients        |            |                    |       |         |                |
| Dry matter                        | 0.89a      | 0.79b              | <.01  | <.001   | 0.45           |
| Crude protein                     | 0.88a      | 0.78b              | <.01  | <.001   | 0.54           |
| Aether extract                    | 0.60a      | 0.55b              | <.01  | .002    | 0.44           |
| Neutral detergent fibre           | 0.66a      | 0.46b              | <.01  | <.001   | 0.39           |
| Acid detergent fibre              | 0.68a      | 0.44b              | 0.01  | <.001   | 0.38           |
| Ash                               | 0.53a      | 0.49b              | 0.01  | .050    | 0.44           |
| Calcium                           | 0.49a      | 0.37b              | 0.02  | .006    | 0.33           |
| Total phosphorus                  | 0.44       | 0.42               | 0.02  | .558    | 0.32           |
| Gross energy                      | 0.88a      | 0.75b              | <.01  | <.001   | 0.35           |
| Organic matter                    | 0.91a      | 0.81b              | <.01  | <.001   | 0.46           |
| Energy utilization variablesc     |            |                    |       |         |                |
| Total feed intake, kg             | 10.58      | 10.39              | 0.18  | .472    |                |
| Gross energy intake, MJ           | 167.14     | 172.18             | 2.95  | .255    |                |
| Dry faeces output, kg             | 1.04a      | 1.87b              | 0.17  | <.001   |                |
| Gross energy in dry faeces, MJ/kg | 19.41a     | 22.64b             | 0.48  | <.001   |                |
| Faecal gross energy output, MJ    | 20.13a     | 42.45b             | 0.89  | <.001   |                |
| Urine output, kg                  | 12.54a     | 7.60b              | 3.06  | .026    |                |
| Gross energy in urine, MJ/kg      | 0.11       | 0.24               | 0.05  | .088    |                |
| Urinary gross energy output, MJ   | 1.26       | 1.46               | 0.25  | .583    |                |

Values are means of six observations per treatment.

Values represent total intake and output of each variable over a 5d collection period that followed a 7d diet adaptation period in growing pigs (50.3 ± 1.1 kg body weight). The basal diet contained 973.0 g/kg corn and soybean meal, and the treatment diet contained to contain 194.6 g/kg TP which replaced corn and soybean meal in the basal diet.

3.3. Effects of increasing energy density in tomato pomace on antioxidant indicators, physiological and biochemical indexes of serum in growing pigs

There was no effect of tomato pomace inclusion, with or without added SBO, on MDA, SOD, T-AOC, SUN, HDL-C, TC, ALB, and AST. CREA increased linearly (P < .05) with increasing TP inclusion. GSH-Px and GLU tended to linearly decreased (0.05 < P < .1) with increasing TP inclusion. TG, total protein, and GLB tended to linearly increased (0.05 < P < .1) with increasing TP inclusion. The A/G was improved (P < .05) with SBO only at TP 100 g/kg inclusion. The GSH-Px was tended to reduce (0.05 < P < .1) and ALT was tended to improve (0.05 < P < .1) with SBO only at TP 100 g/kg inclusion.

4. Discussion

4.1. Nutrient content, DE, ME, and nutrient digestibility of tomato pomace

Tomato pomace has a high fibre content and dietary fibre is a key factor for nutrient utilization in the diet (Noblet and Senach 2006), because it is resistant to mammalian digestive enzymes in the small intestine and can only be partially fermented in the hindgut. In the present study, dietary inclusion of TP increased NDF and ADF content compared with the corn-soybean meal basal diet, which explains the increase in faecal output. This is consistent with previous reports (Wilfart et al. 2007a) and is related to the water holding capacity of soluble dietary fibre. Insoluble dietary fibre increases faecal bulk (Serena et al. 2008). Consequently, higher faecal gross energy resulted in lower DE and ME content and total tract nutrient digestibility.

4.2. Effects of tomato pomace on growth performance and nutrient digestibility for growing pigs

There was no significant difference in final BW or ADFI between the treatments when diet contain 50 or 100 g/kg TP. The lack of difference in pig performance with dietary TP inclusion is consistent with several reports using tomato pomace as replacements for other ingredients without adverse impact on growth performance (Caluya et al. 2000; Cilev et al., 2007; Correia et al. 2017). However, the linear decrease in ADG and G:F with TP inclusion level may be due to the higher dietary fibre content in TP diets because high fibre content of feed ingredients is responsible for a decline
in digestible energy content of feeds for pigs (Noblet and Perez 1993). Supplementation of TP in diets decreased digestibility of nutrients. The digestibility of nutrients in pig diets is related to the type and content of dietary fibre (De et al. 2013). Fibre enhances bowel movement and reduces transit time of digesta. This agrees with the reported study that insoluble dietary fibre decreased retention time of the digesta (Wilfart et al. 2007b). In addition, fibre in tomato by-products is highly insoluble (Shao et al. 2013). The TP used in this study contained more insoluble dietary fibre than soluble dietary fibres. Insoluble dietary fibre is well known to encapsulate nutrients. In addition, monogastric animals do not enzymatic capability to digest these fibres; therefore, in the present study, the ATTD of DM, EE, NDF, ADF, GE and OM were negatively correlated with TP contents, which was consistent with the results from previous research which showed that growing pigs fed diets containing tomato pomace, nutrient digestibility was significantly reduced (Imamidou et al. 1999). Therefore, increasing insoluble dietary fibre content is typically negatively correlated with digestibility and the energy content of feedstuffs (Table 6).

### 4.4. Effects of increasing energy density in tomato pomace on serum parameters

Changes in serum biochemical indicators reflect changes in the body’s metabolic function. When the diet contained 100 g/kg TP, increasing energy density had significant effects on GLB and A/G. The linear increase serum GSH-Px implies some antioxidant component exists in TP, such as carotenoid. This is consistent with previous study that indicated using tomato pomace to increase pork oxidative stability (Correia et al. 2017). The levels of ALT and AST are tools in the diagnosis of liver function. There was no effect of TP inclusion on serum AST and ALT, which indicate that TP inclusion benefits to metabolism in liver and the health of growing pigs. Concentrations of total cholesterol, SUN, and total protein in blood reflect the health and nutritional status of pigs (Etim et al. 2014; Hlatini and Chimonyo 2016). In our results, total cholesterol, SUN, and total protein were not affected among treatments. Their results indicate that TP inclusion had no negative impact on the health and nutritional status of growing pigs. In our results, CREA, indicators of kidney health, was linearly increased as TP inclusion level, but there were no significant differences among treatments. In addition,
Table 7. Effect of tomato pomace on serum physiological and biochemical indicators in Exp. 2a.

| Item     | Basal | −SBO | +SBO | SEM | P-value | Linear | Quadratic | 50 g/kg TP | 100 g/kg TP |
|----------|-------|------|------|-----|---------|--------|-----------|------------|-------------|
| GSH-Px, U/mL | 801.73 | 864.4 | 872.37 | 934.56 | 785.99 | 51.52 | .282 | .090 | .954 | .920 | .091 |
| MDA, nmol/mL | 2.97 | 3.31 | 3.77 | 2.9 | 3.09 | 0.32 | .336 | .834 | .230 | .510 | .382 |
| SOD, U/mL | 81.46 | 84.39 | 81.88 | 78.52 | 75.54 | 4.36 | .660 | .700 | .508 | .585 | .498 |
| T-AOC, U/mL | 11.05 | 10.33 | 10.03 | 9.67 | 9.83 | 0.61 | .537 | .150 | .973 | .690 | .866 |
| GLU, mmol/L | 3.72 | 2.73 | 2.35 | 3.62 | 3.54 | 0.22 | .283 | .057 | .512 | .418 | .852 |
| SUN, mmol/L | 6.32 | 6.67 | 5.60 | 6.13 | 6.71 | 0.67 | .794 | .396 | .837 | .433 | .592 |
| CREA, umol/L | 40.83 | 42.02 | 39.74 | 36.24 | 38.05 | 0.61 | .731 | .562 | .743 | .638 | .218 |
| AST, mmol/L | 6.72 | 6.45 | 6.13 | 5.97 | 6.05 | 0.11 | .230 | .090 | .421 | .245 | .536 |
| ALT, mmol/L | 4.95 | 5.74 | 5.32 | 4.83 | 5.05 | 0.23 | .283 | .090 | .421 | .245 | .536 |
| GLU, mmol/L | 2.95 | 3.47 | 3.25 | 3.62 | 3.54 | 0.23 | .283 | .090 | .421 | .245 | .536 |
| T-AOC, U/mL | 11.05 | 10.33 | 10.03 | 9.67 | 9.83 | 0.61 | .537 | .150 | .973 | .690 | .866 |
| SOD, U/mL | 81.46 | 84.39 | 81.88 | 78.52 | 75.54 | 4.36 | .660 | .700 | .508 | .585 | .498 |
| GSH-Px, U/mL | 801.73 | 864.4 | 872.37 | 934.56 | 785.99 | 51.52 | .282 | .090 | .954 | .920 | .091 |

Notes: TP, tomato pomace; SBO, soybean oil; GSH-Px, glutathione peroxidase; MDA, malondialdehyde; SOD, superoxide dismutase; T-AOC, total antioxidant capacity; GLU, glucose; SUN, serum urea nitrogen; CREA, creatinine; HDL-C, high-density cholesterol; TC, total cholesterol; TG, total triglyceride; TP, total protein; ALB, albumin; GLB, globulin; A/G, albumin/globulin ratio; AST, glutamic oxalacetic transaminase; ALT, glutamic-pyruvic transaminase.

Values are means of six observations per treatment. Pigs were provided experimental diets for 28d. +SBO indicates addition of SBO to TP diets such that digestible energy content was equivalent to basal diet.

Linear and quadratic analysis based on TP diets without additional SBO.

Pre-planned comparisons between diets containing equivalent TP with and without added SBO.

The tendency for a linear increase in total protein and GLB with dietary TP inclusion, which implies TP strengthens immune function. These results indicate that appropriately TP inclusion was beneficial to metabolism and the health of growing pigs.

5. Conclusion

The findings of the study showed that increasing dietary energy concentration can largely eliminate the negative effects of fibre in tomato pomace. The optimal supplementation of TP in diets in this study is 50 g/kg for growing pigs. Utilization of tomato processing by-products as a novel feedstuff may provide economic benefit and reduce problems with waste disposal.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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