Effects of yeast-derived protein vs spray-dried porcine plasma supplementation on growth performance, metabolism and immune response of weanling piglets

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Abstract

A total of 160 weaned pigs (PIC 327×1050, 7.35±0.50 kg body weight) were randomly assigned to four dietary treatments: i) control, a basal diet; ii) spray-dried porcine plasma (SDPP) diet, basal diet containing 4% SDPP; iii) SDPP plus yeast-deprived protein (YP) diet, basal diet containing 2% SDPP and 2% YP; and iv) YP diet, basal diet containing 4% YP. During the first week, average daily feed intake in piglets fed SDPP diet was markedly higher than piglets fed basal diet (+10%, P<0.05) and YP diet (+12%, P<0.05), but incidence of scour was higher than that in piglets fed YP diet. As a result, average daily gain (ADG) in piglets fed SDPP diet was similar to other groups, but ADG in piglets fed SDPP plus YP diet was higher than that in piglets fed basal diet (+13%, P<0.05). Serum levels of urea nitrogen and triglyceride were significantly decreased in piglets fed diet containing SDPP or YP relative to piglets fed basal diet (16~54% lower, P<0.05). Moreover, feeding YP diet markedly decreased serum levels of cortisol (relative to basal and SDPP plus YP diet, P<0.05) and C-reactive protein (relative to other groups, P<0.05) at d 7 post-weaning. Based on the results of this experiment, SDPP and partially substituting SDPP by YP are beneficial for growth performance of piglets, which may be ascribed to the improved metabolic status and humoral immune response. Moreover, weaning stress-related parameters were profoundly reduced by feeding YP diet.

Introduction

Weaning is a crucial phase in pig production systems, and is frequently associated with poor performance, inflammation and diarrhea, which are mainly ascribed to the immaturity of digestive and immune system as well as the nutritional and environmental changes (Gao et al., 2011; Martinez-Puig et al., 2007). Various strategies have been employed to improve feed intake and health status after weaning. High quality protein sources have been widely used to alleviate weaning stress, improve growth performance and immune function of piglets (Che et al., 2012). Spray-dried porcine plasma (SDPP) is a common protein source in starter diets for weaned piglets in many countries (Niewold et al., 2007). Considerable studies have shown that SDPP improves growth performance and immunity by its palatability and immunoglobulin fractions (Bergstrom et al., 1997; Coffey and Cromwell, 1995; Ermer et al., 1994). However, the use of SDPP in pig industry has been inhibited in China and other regions such as European countries, considering its potential bio-security risk and high cost (Che et al., 2012; Van Dijk et al., 2001). Yeast-derived protein (YP), as a yeast content separated from yeast cells, has been proposed to be a superior protein ingredient to substitute SDPP for weaning piglets (Chae et al., 2004). Yeast-derived protein generally contains amino acids and nucleotides, which have been demonstrated to possess immunoregulatory and antimicrobial capabilities (De los Santos et al., 2012). Previous studies demonstrated that YP had similar effects as SDPP in increasing feed intake and body weight (BW) gain of weaning piglets (Carlson et al., 2005; Moehn et al., 2010), which nutritionally was associated with their similar digestibility of nutrients (Mateo and Stein, 2007). However, the metabolism and immunological differences by feeding SDPP and YP diets have not been studied in weaning piglets. Therefore, the objectives of this study were to compare the effects of YP or SDPP on growth performance, metabolism and immune response of weaning piglets.

Materials and methods

The experiment followed the actual law of animal protection and was approved by the Animal Care and Use Committee of the Sichuan Agricultural University, and was performed in accordance with the National Research Council’s guide for the care and use of laboratory animals.

Experimental design and dietary treatments

The experiment was designed as a complete randomised study comprising of four dietary treatments. A total of 160 barrows and gilts (PIC 327×1050, initially 7.35±0.50 kg BW and 28±2 d of age) were randomly allocated to one of the 4 dietary treatments. The dietary treatments were as follows: i) control, a basal diet; ii) SDPP diet, basal diet containing 4% SDPP; iii) SDPP plus YP diet, basal diet containing 2% SDPP and 2% YP; and iv) YP diet, basal diet containing 4% YP. Each treatment had 5 pens and 8 piglets each pen. Piglets were housed in fully slatted pens (2.65×2.05 m). The YP (Tangshan Top Bio-Technology Co., Tangshan, China) was derived from Saccharomyces cerevisiae: the nutrients composition of YP is presented in Table 1. During the 4-wk feeding period, all piglets were housed in the temperature-controlled nursery room (25~27°C). The piglets were fed ad libitum from a four-space feeder (1.25×0.25×0.10 m) with trays placed underneath the feeders in order to avoid wastage of feed. Water was available ad libitum from nipple drinkers. Diets were formulated to meet nutrient requirements of piglets.

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Key words: Pigs, Weaning, Spray-dried porcine plasma, Yeast-derived protein, Humoral immune response.

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proposed by the National Research Council (Table 2). The nutritive values of individual ingredients used for dietary formulation were taken from tabulated values, while crude protein (CP) and amino acids of YP were analysed, except digestible energy (DE) was calculated from digestible nutrient contents (Spiehs et al., 2002).

Individual piglet BW was recorded weekly, and feed consumption was recorded daily on a pen basis during the experiment to calculate average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR). At d 7, blood samples were collected from the cervical vein into non-heparinised vacuum tubes (Chengwu Xian Medical Products Factory, Shangdong, China) from one piglet each pen, and the same piglets were sampled again on the final day (d 28) of the experiment. After collection, the blood samples in the non-heparinised vacuum tubes were centrifuged (3000×g) for 15 min at 4°C. Serum samples were stored at -80°C for biochemical assays. Subjective diarrhoea scores were recorded daily from d 1 to 28 based on the methods modified from Owusu-Asiedu et al. (2002). Feces appearance of pig anal orifice was examined daily for diarrhoea scores (0, 1, 2 and 3 for normal or dry, pasty, semiliquid and watery, respectively). Any piglet with a score of 2 or 3 was considered to be in diarrhoea. Scores were recorded on a pen basis following observations of individual piglet and signs of stool consistency in the pen. The score is reported as average daily diarrhoea score of individual piglet. The incidence of diarrhoea was observed and recorded and these observations were used to calculate a diarrhoea index (DI) using the following equation: DI=the sum of diarrhoea scores/the sum of the total number of trial piglets (Kelly et al., 1990).

**Measurement of serum biochemical parameters**

Serum was separated on-site and was stored at -80°C until it was analysed (within 3 to 4 weeks). Serum glucose concentrations at the end of the experiment were determined by colorimetric methods after an enzymatic reaction with peroxidase (Randox, Antrim, UK). Serum ura nitrogen (SUN) was analysed by the biochemical analytical instrument (Hitachi 7170; Hitachi, Tokyo, Japan). Serum total cholesterol (TC) and triglyceride (TG) were analysed enzymatically using Pureauto S TC-N (Daichi Chemicals, Tokyo, Japan) and Determiner L TG (Kyowa Medex, Tokyo, Japan), respectively. High-density lipoprotein-cholesterol (HDL-C) was determined using direct method and determiner L HDL-C (Kyowa Medex). All samples were measured using an automatic analyser (AU5400; Olympus, Tokyo, Japan). Low-density lipoprotein-cholesterol (LDL-C) was estimated using the formula by Cui et al. (2005). The interassay coefficient of variation for determinations of TC, TG, HDL-C and LDL-C range were 3.0, 3.0, 5.0 and 5.0% lower, respectively. The procedures followed the manufacturers’ instructions. All measurements were conducted in duplicate.

**Analysis of serum C-reactive protein, cortisol and immunoglobulins**

Commercial ELISA kits (Bio-tech Inc., Hubei, China) were used to measure serum C-reactive protein (CRP) concentrations. Each serum sample was analysed in duplicate. The plate wells were added 100 μL of standard and serum samples. Each well was then added 50 μL of enzyme conjugate for CRP, sealed and mixed prior to incubation at 37°C for 30 min. Then all wells were manually washed with deionised water 5 times. The plate was inverted and blot dried by absorbent paper. Afterwards, 50 μL of Chromogen Solution A and Chromogen Solution B (respectively) were added to each well and incubated in dark at 37°C for 15 min. This was followed by addition of 50 μL of Stop solution and then the wells were completely mixed. The optical density (OD) value was read at 450 nm within 15 min (MuLtisKan MK3; Thermo Labsystems, Milford, MA, USA) for both standards and serum samples. C-reactive protein concentration was calculated according to the standard curve which was obtained by plotting OD value for each standard (y-axis) against the CRP concentration (x-axis). The similar procedure was used to measure serum cortisol, IgA, IgM and IgG concentrations except the respective enzyme conjugates for cortisol, IgA, IgM and IgG were used. The minimal detection limit was 10 μg/L for CRP, 3 μg/L for cortisol, 5 μg/mL for IgA, 20 μg/mL for IgM and 5 μg/mL for IgG, respectively.

**Statistical analysis**

Data were expressed as means±SEM. All data were subjected to one-way analysis of variance (ANOVA) and Fisher’s least significant difference (LSD) test was applied as a *post-hoc* test to determine treatment differences. The data analysed included ADG, ADFI and FCR with each pen as statistic unit, while serum biochemical parameters, CRP, cortisol and immunoglobulin analysis with one piglet each pen as statistic unit and 5 piglets each treatment group. A probability level of P<0.05 was considered significant.

### Results and discussion

During the first week after weaning, piglets fed SDPP diet had increased ADFI (388 vs 352 g, +10%, and 388 vs 347 g, +12%, P<0.05, respectively) relative to piglets fed basal and YP diet, but comparable as piglets fed SDPP plus YP diet which had markedly higher ADG (310 vs 274 g, +13%, P<0.05) than piglets in control (Table 3). The beneficial effect on growth performance by SDPP in diet is consistent with previous studies with improvements in ADG and ADFI during the first week (Coffey and Cromwell, 2001; Pierce et al., 2005).

#### Table 1. Measured composition of yeast-derived protein.

| Ingredients | Contents |
|-------------|----------|
| Crude protein, % | 53.20 |
| Crude fat, % | 2.90 |
| Carbohydrate, % | 32.60 |
| Ash content, % | 7.00 |
| Crude fibre, % | 0.50 |
| Dry matter, % | 97.03 |
| Inosine, g/kg | 1.02 |
| Amino acids, % | 5.09 |
| Glutamic acid | 4.26 |
| Aspartic acid | 3.65 |
| Leucine | 2.58 |
| Alanine | 3.42 |
| Lysine | 2.46 |
| Valine | 0.91 |
| Arginine | 2.24 |
| Proline | 2.19 |
| Serine | 1.96 |
| Phenylalanine | 2.11 |
| Isoleucine | 2.43 |
| Threonine | 1.92 |
| Tyrosine | 1.84 |
| Histidine | 1.20 |
| Methionine | 0.71 |
| Tryptophan | 0.55 |
| Cystine | 1.04 |
| Nucleotide, g/kg | 8.40 |
| GMP | 5.97 |
| UMP | 0.34 |
| CMP | 24.70 |
| AMP | 1.06 |

GMP, guanosine monophosphate; UMP, uridine monophosphate; CMP, cytosine monophosphate; AMP, adenosine monophosphate. Amino acids of yeast-derived protein were analysed at PONY Testing International Group (Beijing, China; report ID: W10201050061DD), and contents of GMP, UMP, CMP and AMP were analysed at China National Analytical Center (Guangzhou, China; report ID: 20101107F-b). The contents of thymidine and inosine monophosphates were undetected (detection limit of 0.05 g/kg).
Meanwhile, increased feed consumption by feeding SDPP has been attributed to its palatability or the health-promoting effect (Van Dijk et al., 2001). However, feeding VP diet markedly decreased feed intake, suggesting the poor palatability which may be related to the components of VP, the low molecular peptides and free amino acids can be variable due to the processing procedures of VP (Chae et al., 2001; Thanissery et al., 2010). There is possibility that some elements with poor flavour or tastes may restrict the feed intake of weaning piglets. Supportively, Pereira et al. (2012) indicated that the inclusion of VP can only partially replace blood plasma in piglet diets without compromising body weight gain and FCR. Moreover, Reisinger et al. (2012) showed that the lower (0.1%) concentration of the yeast derivatives had a positive influence on the performance parameters of the broiler compared to those fed 0.2% yeast derivatives.

In this study, unexpectedly, piglets fed SDPP diet had markedly higher incidence of diarrhea (+127%, P<0.05) than piglets fed VP diet during the first week (Table 4), which may be associated with the increasing ADFI by feeding SDPP diet, considering the excessive intake of solid feed was not suitable for the immature gastrointestinal system of piglets, especially during the first days post-weaning (Pluske et al., 1997). These findings may also explain why ADFI of piglet fed SDPP diet was higher than piglets fed VP diet but ADG was comparable between these two treatments. In addition, the VP-containing nucleotides have been demonstrated to prevent post-weaning diarrhea, improve intestinal inflammation, immune response and anti-oxidative capability of piglets (Martinez-Puig et al., 2007; Salobir et al., 2005; Superchi et al., 2012).

Table 2. Composition and nutrient contents of the experimental diets.

| Item                  | Basal diet | SDPP diet | SDPP plus VP diet | VP diet |
|-----------------------|------------|-----------|-------------------|---------|
| Ingredients, %         |            |           |                   |         |
| Corn                  | 60.10      | 60.60     | 59.80             | 59.10   |
| Soybean meal, 46% CP  | 15.00      | 15.00     | 15.00             | 15.50   |
| Soy protein concentrate, 65% CP | 7.00      | 6.50     | 7.00              | 7.00    |
| Fish meal, 63% CP     | 5.00       | 1.00      | 1.00              | 1.00    |
| Dehydrated whey, 80% lactose | 6.00     | 6.00      | 6.00              | 6.00    |
| Soybean oil           | 3.00       | 2.80      | 2.70              | 2.80    |
| Limestone             | 1.00       | 1.30      | 1.30              | 1.28    |
| Calcium dihydrogenphosphate | 0.50    | 0.70      | 0.80              | 0.80    |
| NaCl                  | 0.12       | 0.12      | 0.20              | 0.20    |
| Zinc oxide            | 0.30       | 0.30      | 0.30              | 0.30    |
| Choline chloride, 50% | 0.10       | 0.10      | 0.10              | 0.10    |
| Lysine, 98.5%         | 0.32       | 0.28      | 0.34              | 0.40    |
| Methionine, 98.5%     | 0.12       | 0.08      | 0.12              | 0.15    |
| Threonine, 9%         | 0.18       | 0.14      | 0.18              | 0.20    |
| Tryptophan, 10%       | 0.22       | 0.10      | 0.12              | 0.20    |
| SDPP                  | -          | 4.00      |                   | -       |
| VP                    | -          | -         | 2.00              | 4.00    |
| Compound premix*      | 1.00       | 1.00      | 1.00              | 1.00    |
| Total                 | 100.00     | 100.00    | 100.00            | 100.00  |

Nutrient content

| Item          | Basal diet | SDPP diet | SDPP plus VP diet | VP diet  |
|---------------|------------|-----------|-------------------|--------|
| DE, kcal/kg   | 3400       | 3400      | 3400              | 3400   |
| Crude protein, % | 20.00     | 20.00    | 20.00             | 20.00  |
| Ca, %         | 0.80       | 0.80      | 0.80              | 0.80   |
| Available P, % | 0.40      | 0.40      | 0.40              | 0.40   |
| Salt, %       | 0.40       | 0.40      | 0.40              | 0.40   |
| Crude fat, %  | 5.50       | 5.50      | 5.50              | 5.50   |
| Choline, g/kg | 1.50       | 1.50      | 1.50              | 1.50   |
| Lysine, %     | 1.44       | 1.44      | 1.44              | 1.44   |
| Methionine and cysteine, % | 0.80 | 0.80 | 0.80 | 0.80 |
| Threonine, %  | 0.97       | 0.97      | 0.97              | 0.97   |
| Tryptophan, % | 0.25       | 0.25      | 0.25              | 0.25   |

SDPP, spray-dried porcine plasma, containing 196.8 g/kg AEC in SDPP (China National Feed Quality Control Center, Wuhan, China; report ID: 20130204); VP, yeast-derived protein; CP, crude protein; DE, digestible energy; P, phosphorus. "Compound premix contained the following per kilogram of diet: Fe, 150 mg; Cu, 195 mg; Zn, 150 mg; Mn, 30 mg; I, 0.3 mg; Se, 0.3 mg; vitamin A, 12000 IU; vitamin D3, 3200 IU; vitamin E, 80 IU; vitamin K, 32.50 mg; vitamin B1, 2.50 mg; vitamin B2, 6.50 mg; vitamin B5, 5 mg; vitamin B6, 50 mg; acetic acid, 45 mg; pantothenic acid, 20 mg; folic acid, 1.50 mg; biotin, 0.15 mg; enzyme preparation and preservatives. Digestible energy was calculated according to digestible nutrient contents.

Table 3. Effects of feeding spray-dried porcine plasma or yeast-derived protein on growth performance of weaning piglets.

| Item          | Basal diet | SDPP diet | SDPP plus VP diet | VP diet |
|---------------|------------|-----------|-------------------|--------|
| Initial BW, kg | 7.37±0.03  | 7.33±0.06 | 7.36±0.03         | 7.37±0.02 |
| Final BW, kg  | 21.03±0.78 | 22.24±0.62| 22.26±0.30        | 21.20±0.31 |
| ADFI, g/d     | 352±15ab   | 388±7abc  | 383±12abc         | 347±11b  |
| ADG, g/d      | 274±17b    | 306±5abc  | 310±12b           | 280±8b   |
| FCR           | 1.30±0.08  | 1.27±0.03 | 1.23±0.02         | 1.23±0.02 |
| d 0-7         |            |           |                   |         |
| ADFI, g/d     | 471±25     | 513±6     | 488±11            | 486±18   |
| ADG, g/d      | 379±20     | 409±12    | 399±11            | 382±7    |
| FCR           | 1.24±0.03  | 1.26±0.04 | 1.23±0.02         | 1.28±0.06 |
| d 0-14        |            |           |                   |         |
| ADFI, g/d     | 576±33     | 633±13    | 614±14            | 595±16   |
| ADG, g/d      | 441±20     | 468±10    | 476±11            | 440±14   |
| FCR           | 1.31±0.04  | 1.35±0.02 | 1.29±0.03         | 1.36±0.04 |
| d 0-21        |            |           |                   |         |
| ADFI, g/d     | 678±38b    | 753±15b   | 733±13b           | 704±17b  |
| ADG, g/d      | 488±28     | 533±10    | 532±10            | 490±11   |
| FCR           | 1.39±0.01  | 1.41±0.01 | 1.38±0.02         | 1.43±0.03 |

SDPP, spray-dried porcine plasma; VP, yeast-derived protein; BW, body weight; ADFI, average daily feed intake; ADG, average daily growth; FCR, feed conversion ratio. Values are mean (±SEM) of 5 pens with 8 pigs each per treatment. Means within a row with different letters are significantly different (P<0.05) as determined by Fisher’s least significant difference test.
piglets had been also ascribed to the lower protein catabolism by microbiota (Jiang et al., 2000a, 2000b). Consistent with previous reports, therefore, the markedly lower level of SUN in piglets fed SDPP- and YP-diet indicates the increasing utilisation of dietary protein for body protein synthesis. Furthermore, energy metabolism status of piglets fed SDPP diet may be optimised, as indicated by the lower serum level of TG (29%, P<0.05) compared to pigs fed control diet (Table 5), which may be also associated with metabolism of ingested fat (Jones et al., 1997; Perez-Bosque et al., 2004).

In our previous study, serum level of cortisol has been successfully measured to reflect the stress-relief effect of dietary treatments in weaning piglets (Che et al., 2012). Compared with piglets fed control diet and SDPP plus YP diet, feeding YP diet (P<0.05) markedly decreased serum cortisol level of piglets at d 7 post-weaning (Table 6), implying that YP could be an effective protein source to relieve weaning stress. The nucleotides from YP should play an important role in alleviating weaning stress. Superchi et al. (2012) indicated that dietary supplementation of nucleotides could promote the adaptive response of piglets to weaning via reducing plasma level of cortisol, also inhibiting potential inflammatory response by regulating peripheral blood mononuclear cells cytokine expression. Similarly, CRP is an acute phase serum protein mediating innate and adaptive immunity (Pineiro et al., 2007). The serum level of CRP has been clinically used in pigs to monitor inflammation and infection (Gutierrez et al., 2009). In this present study, the markedly lower serum level of CRP in piglets fed YP diet (P<0.05) further supports the notion that YP-diet is able to alleviate weaning stress of piglets (Table 6).

Humoral immunity was determined by analysing serum levels of IgG, IgA and IgM in piglets receiving different protein sources. We found piglets fed SDPP diet had 1–1.5 fold higher level of IgG (P<0.05) (Table 6) than piglets fed other diets, such a higher level of IgG could be contributed by SDPP, which was reported to contain 107.3~225.0 g/kg of IgG (Pierce et al., 2005; Rodriguez et al., 2010). Differing with IgG being mainly synthesized in bone marrow, a larger proportion of serum levels of IgA and IgM are derived from intestinal immunocytes in species such as pigs, rats and rabbits (Craig and Cebra, 1971; Vaerman et al., 1973). Therefore, the increasing serum levels of IgM and IgA may be associated with the improved intestinal immunity resulting from the synergistical effect by combining SDPP with YP. The nucleotides in YP were reported to have immunomodulatory effect on gut local immunity (De los Santos et al., 2007; Gil, 2002; Thanissery et al., 2010).

### Table 4. Effect of feeding spray-dried porcine plasma or yeast-derived protein on the incidence of scour of weaning piglets.

| Item                          | Basal diet | SDPP diet | SDPP plus YP diet | YP diet |
|-------------------------------|------------|-----------|-------------------|--------|
| d 0-7                         | 0.18±0.04a | 0.25±0.04b | 0.19±0.03a        | 0.11±0.03a |
| d 0-14                        | 0.22±0.06  | 0.21±0.03  | 0.26±0.06         | 0.12±0.02    |
| d 0-21                        | 0.22±0.05  | 0.19±0.03  | 0.22±0.05         | 0.12±0.01    |
| d 0-28                        | 0.18±0.05  | 0.16±0.02  | 0.17±0.04         | 0.10±0.01    |

SDPP, spray-dried porcine plasma; YP, yeast-derived protein. Values are mean (±SEM) of 5 pens with 8 pigs each per treatment. Means within a row with different letters are significantly different (P<0.05) as determined by Fisher’s least significant difference test.

### Table 5. Serum concentrations of glucose, serum urea nitrogen, triglyceride, total cholesterol, high- and low-density cholesterol in the various groups at the end of the experiment.

| Item                          | Basal diet | SDPP diet | SDPP plus YP diet | YP diet |
|-------------------------------|------------|-----------|-------------------|--------|
| Glucose, mmol/L               | 4.58±0.77  | 5.30±0.70  | 5.32±0.46         | 4.66±0.67  |
| SUN, mmol/L                   | 6.63±0.70b | 3.05±0.53b | 3.34±0.32b        | 3.65±0.41b  |
| TG, g/L                       | 0.75±0.06b | 0.53±0.06b | 0.62±0.03b        | 0.63±0.06b  |
| TC, g/L                       | 2.11±0.16  | 2.05±0.10  | 2.08±0.11         | 2.15±0.09   |
| HDL-C, g/L                    | 0.91±0.06  | 0.86±0.05  | 0.98±0.05         | 0.94±0.10   |
| LDL-C, g/L                    | 1.18±0.15  | 1.22±0.05  | 1.15±0.06         | 1.22±0.06   |

SDPP, spray-dried porcine plasma; YP, yeast-derived protein; SUN, serum urea nitrogen; TG, triglyceride; TC, total cholesterol; HDL-C, high-density lipoprotein-cholesterol; LDL-C, low-density lipoprotein-cholesterol. Values are mean (±SEM) of three replicates per serum sample. Means within a row with different letters are significantly different (P<0.05) as determined by Fisher’s least significant difference test.

### Table 6. Effects of feeding spray-dried porcine plasma or yeast-derived protein on immune response at different ages of weaning piglets.

| Item                          | Basal diet | SDPP diet | SDPP plus YP diet | YP diet |
|-------------------------------|------------|-----------|-------------------|--------|
| Cortisol, µg/L                | 22.38±3.17b| 16.29±1.30a| 19.24±2.88b       | 11.06±1.94a |
| d 7                           | 17.52±1.73 | 15.71±0.27 | 16.89±1.82        | 15.07±2.29  |
| CRP, µg/L                     | 742.18±45.87c| 561.98±34.74b| 653.96±36.29c     | 374.35±22.91c |
| d 7                           | 447.21±42.89 | 441.83±62.36 | 390.86±64.19     | 388.41±36.97  |
| IgG, µg/mL                    | 53.86±2.15a | 104.68±5.97 | 41.50±1.92        | 63.68±8.21a  |
| d 7                           | 48.54±2.41a | 89.11±3.40 | 42.55±1.76        | 45.42±3.46   |
| IgM, µg/mL                    | 28.26±2.06c | 24.01±1.11c | 28.49±0.45c       | 17.84±1.03c  |
| d 7                           | 29.74±3.41b | 32.94±2.57b | 39.22±0.82c     | 24.34±0.28c  |
| IgA, µg/mL                    | 25.06±0.57c | 17.98±1.00d | 20.73±2.63c       | 14.95±1.08c  |
| d 7                           | 22.59±2.94a | 23.40±2.34a | 28.45±0.38c     | 18.10±0.58a  |

SDPP, spray-dried porcine plasma; YP, yeast-derived protein; CRP, C-reactive protein; IgG, immunoglobulin G; IgM, immunoglobulin M; IgA, immunoglobulin A. Values are mean (±SEM) of three replicates per serum sample. Means within a row with different letters are significantly different (P<0.05) as determined by Fisher’s least significant difference test.
Conclusions

It can be concluded that feeding SDPP or partially substituting SDPP by YP could enhance growth performance of piglets through improving metabolic status and humoral immunity. However, weaning stress at the first week post-weaning was alleviated by feeding YP diet, as indicated by the marked lower levels of cortisol and C-reactive protein.

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