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Use of insect powder as a source of dietary protein in early-weaned piglets[1]

Y. J. Ji,*[2] H. N. Liu,*[2] X. F. Kong,*[3] F. Blachier,† M. M. Geng,* Y. Y. Liu,* and Y. L. Yin*[3]

*Key Laboratory of Agro-ecological Processes in Subtropical Region, Hunan Provincial Engineering Research Center of Healthy Livestock and Poultry, Institute of Subtropical Agriculture, Chinese Academy of Sciences, Changsha, Hunan 410125, China; and †INRA, CNRH-IdF, AgroParisTech, UMR 914 Nutrition Physiology and Ingestive Behavior, 16 rue Claude Bernard, Paris 75005, France

ABSTRACT: In the present study, 5% powders of *Tenebrio molitor* (TM), *Musca domestica* larvae (MDL), or *Zophobas morio* (ZM) were used as a source of dietary protein in piglets weaned at 14 ± 2 d of age instead of 5% plasma protein powder in the basal diet (4 groups with 6 replicates of 6 piglets). Growth performance, diarrhea rate, plasma biochemical parameters, and apparent ileal digestibility (AID) were determined on Days 28 and 56 after the initiation of treatment. The ADFI in the TM and MDL groups on Day 7 were decreased ($P < 0.05$) whereas the ADFI in the ZM group on Days 28 and 56 were increased ($P < 0.05$) compared with the respective values in the control group. Diarrhea rates in all of the insect groups from Days 15 through 28 were decreased ($P < 0.05$) compared with those in the control group. On Day 28, the plasma ammonia concentration in all of the insect groups was decreased ($P < 0.05$) compared with that in the control group. On Day 56, plasma concentrations of total protein and albumin were decreased ($P < 0.05$) in the ZM group whereas the Met AID in all of the insect groups was increased ($P < 0.05$) compared with those in the control group. There was no difference ($P > 0.05$) in nutrient AID on Day 28 compared with the control group, except for Ile and Met. Collectively, these findings indicate that the use of insect powder as a source of dietary protein is associated with apparent good bioavailability of several AA and a reduced diarrhea rate in early-weaned piglets without affecting growth performance.

Key words: amino acid, diarrhea, insect, protein source, weaned piglet

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INTRODUCTION

A possible scarcity of protein resources as well as regulation of antibiotics use for animal production are problems that the world may face in the near future in light of the rapid increase in world population (Koning et al., 2008). Plasma protein, used as a source of protein in animal feed, is well known to represent a biohazard due to possible viral contamination and environmental pollution (Polo et al., 2013). Therefore, alternative protein sources for livestock are likely to be urgently needed. As a full or partial replacement for plasma protein in feed, insect protein appears to be a potential option that possesses several characteristics that make it suitable for use in the porcine diet, such as a high protein level (Yi et al., 2013), good AA profile (Renault et al., 2006), and secure supply with less environmental impact (van Huis, 2013). *Tenebrio molitor* (**TM**), *Musca domestica* larvae (**MDL**), and *Zophobas morio* (**ZM**) are the most common species of insects used in the animal food market and are characterized by rapid reproduction, large biomass, low investment for production, and seasonal reproduction for large-scale production.

Piglet diarrhea is a major cause of postweaning mortality and results in significant economic loss for swine producers (Kong et al., 2014). To reduce the diarrhea rate, the use of high-quality digestible pro-

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[2]These authors contributed equally to this work.

[3]Corresponding authors: nnkxf@isa.ac.cn; yinyulong@isa.ac.cn

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tein with antibacterial compounds in animal feed is required. Insect proteins may be useful for preventing inflammation and mucosal damage (Kang et al., 2011). Therefore, insect protein may represent an interesting protein source to reduce the diarrhea rate in piglets. However, few studies have considered the efficiency of TM, MDL, and ZM as a protein feedstuff in piglets. In this context, the present study evaluated the potential of different insect powders as a feed ingredient for early-weaned piglets. Therefore, the growth performance, diarrhea rate, plasma biochemical parameters, and apparent ileal digestibility (**AID**) of CP and AA were investigated.

MATERIALS AND METHODS

The experimental design and procedures in this study were reviewed and approved by the Animal Care and Use Committee of the Institute of Subtropical Agriculture, Chinese Academy of Science.

Animals and Experimental Treatments

A total of 144 Duroc × Landrace × Yorkshire piglets with an average BW of 4.74 kg were weaned at 14 ± 2 d of age and then randomly assigned to 1 of 4 groups. Each group consisted of 36 piglets arranged in 6 replicates of 6 piglets. The animals received a maize and soybean–based diet formulated based on NRC (1998) requirements that was supplemented with 5% plasma protein powder or 5% powder of TM, MDL, or ZM (listed in Tables 1 and 2). The ingredients and chemical composition of the 4 experimental diets were determined (shown in Tables 1, 2, 3, and 4). Three kinds of insects were provided by Guangdong Entomological Institute (Guangzhou, China). For enzyme destruction, the mature larvae were treated in oven at 105°C for 15 min and then at 65°C for 24 h. After dampening in air for 24 h, the larvae were disintegrated by a crusher and ground with a 100-mm mesh. The analyzed contents (in relative values) of CP in TM, MDL, and ZM were 50.2, 45.6, and 45.1%, respectively; EE averaged 29.0, 30.1, and 41.7%, respectively. Total energy represented 26.2, 26.0, and 28.7 kJ/100 g, respectively. The MDL has the greatest contents of Ca, total P, Fe, and Mn, representing 500.0, 885.7, 1.2, and 3.1 mg/100 g, respectively. The TM had the greatest amount of Cu (1.5 mg/100 g) and Zn (10.5 mg/100 g). The ratio of essential AA to total AA averaged 42.03, 41.71, and 40.35%, respectively. Titanium dioxide (0.1%; Sinopharm Chemical Reagent Co., Ltd., Shanghai, China) was added to all diets as an indigestible marker to determine nutrient digestibility (Yin et al., 2000). For adjustment, commercial creep feed was provided to piglets for 3 d before the experiment. The experiment was divided into 2 stages: Days 1 through 28 and Days 29 through 56. In these 2 stages, the levels of CP in the 4 diets were 21 and 17%, respectively. The piglets were housed in a nursery facility with hard plastic and slatted flooring and had free access to drinking water.

Table 1. Composition and nutrient levels of experimental diets (Phase 1, Days 1–28; as-fed basis)

Ingredients, %	Control	*Tenebrio molitor*	*Musca domestica* larvae	*Zophobas morio*
Corn	62.85	60.45	61.00	60.15
Soybean meal	19.00	19.00	19.00	19.00
Fish meal	6.00	7.50	8.50	7.80
Whey powder	3.00	4.00	2.85	4.00
Plasma protein powder	5.00	–	–	–
Tenebrio molitor powder	–	5.00	–	–
Musca domestica larvae powder	–	–	5.00	–
Zophobas morio powder	–	–	–	5.00
Soybean oil	1.60	1.60	1.40	1.60
$CaHPO_4$	0.60	0.60	0.45	0.55
Limestone	0.65	0.55	0.50	0.60
Salt	0.30	0.30	0.30	0.30
Premix[1]	1.00	1.00	1.00	1.00
Measured nutrient levels, %				
DM	91.27	91.21	91.23	91.33
CP	21.67	20.77	20.23	20.93
Ether extract	4.98	7.46	5.71	6.08
Crude ash	8.03	7.12	7.66	7.42
GE, MJ/kg	17.05	17.53	17.24	17.43

[1]Providing the following vitamins and minerals per kilogram of diet: 12, 000 IU vitamin A, 2, 122 IU vitamin D_3, 29.7 IU vitamin E, 2.8 mg vitamin K_3, 1.2 mg vitamin B_1, 7.1 mg vitamin B_2, 1.3 mg vitamin B_6, 0.03 mg vitamin B_{12}, 42.9 mg nicotinic acid, 21.6 mg pantothenic acid, 0.44 mg folic acid, 0.12 mg biotin, 320 mg choline, 80 mg Fe ($FeSO_4$), 40 mg Cu ($CuSO_4$), 140 mg Zn ($ZnSO_4$), 52 mg Mn ($MnSO_4$), 0.56 mg I (CaI_2), and 0.33 mg Se (Na_2SeO_3).

Sample Collection and Measurements

Body weight and feed intake were measured on Days 1, 8, 15, 29, and 57 after the initiation of dietary supplementation with insect powder. Based on these data, the ADG, ADFI, and F:G ratio were calculated for Days 1 to 7, 8 to 14, 15 to 28, and 29 to 56. Fecal consistency was monitored twice daily (every 12 h) and the nature of excrement and anal swelling were checked. Time and frequency of diarrhea in piglets were recorded as described by Kelly et al. (1990). Diarrhea rate was calculated as the average value in each experimental group.

Table 2. Composition and nutrient levels of experimental diets (phase 2, Days 29–56; as-fed basis)

Ingredients, %	Control	*Tenebrio molitor*	*Musca domestica* larvae	*Zophobas morio*
Corn	66.60	64.70	64.45	64.05
Soybean meal	19.00	19.00	19.00	19.00
Fish meal	2.50	4.00	4.50	4.00
Whey powder	2.60	3.40	3.20	4.00
Plasma protein powder	5.00	–	–	–
Tenebrio molitor powder	–	5.00	–	–
Musca domestica larvae powder	–	–	5.00	–
Zophobas morio powder	–	–	–	5.00
Soybean oil	1.50	1.30	1.35	1.35
$CaHPO_4$	0.90	0.60	0.60	0.60
Limestone	0.60	0.70	0.60	0.70
Salt	0.30	0.30	0.30	0.30
Premix[1]	1.00	1.00	1.00	1.00
Measured nutrient levels, %				
DM	91.56	91.58	91.86	91.41
CP	16.71	16.74	19.36	18.28
Ether extract	3.95	6.37	5.41	6.52
Crude ash	7.43	6.75	7.36	6.92
GE, MJ/kg	16.98	17.36	17.30	17.33

[1]Providing the following vitamins and minerals per kilogram of diet: 12, 000 IU vitamin A, 2, 122 IU vitamin D_3, 29.7 IU vitamin E, 2.8 mg vitamin K_3, 1.2 mg vitamin B_1, 7.1 mg vitamin B_2, 1.3 mg vitamin B_6, 0.03 mg vitamin B_{12}, 42.9 mg nicotinic acid, 21.6 mg pantothenic acid, 0.44 mg folic acid, 0.12 mg biotin, 320 mg choline, 80 mg Fe ($FeSO_4$), 40 mg Cu ($CuSO_4$), 140 mg Zn ($ZnSO_4$), 52 mg Mn ($MnSO_4$), 0.56 mg I (CaI_2), and 0.33 mg Se (Na_2SeO_3).

On Days 28 (phase 1) and 56 (phase 2) after the initiation of dietary supplementation with insect powder, 1 piglet per replicate randomly was chosen (half of barrows and half of gilts in each treatment), and 5 mL blood was drawn from a precaval vein into 10-mL heparin-coated tubes (25 units/mL blood). Plasma was collected after centrifugation for 15 min at 3,000 × *g* at 4°C and stored at –20°C. Plasma levels of albumin (**ALB**), total protein (**TP**), ammonia (**AMM**), and urea nitrogen were detected by a CX4 (Beckman Coulter, Inc.) automatic biochemical analyzer and commercial kits (Leadman Biochemistry Technology Company, Beijing, China) according to the manufacturers' instructions.

After euthanasia, the terminal ileal digesta were collected, homogenized, freeze-dried, and analyzed through a 1-mm mesh screen. The DM and CP in diets as well as ileal digesta were analyzed according to AOAC International (Latimer, 2012) procedures. Titanium oxide contents in diets and digesta were determined, and the AID of nutrients (including CP, DM, and AA as listed in Tables 5 and 6) were calculated

Table 3. Analyzed AA composition of experimental diets (Phase 1, Days 1–28; %, as-fed basis)

Items	Control	*Tenebrio molitor*	*Musca domestica* larvae	*Zophobas morio*
Ala	0.95	1.01	0.98	0.97
Arg	1.09	1.02	1.10	1.12
Asp[1]	1.96	1.82	1.96	2.01
Cys	0.15	0.09	0.13	0.10
Glu[2]	4.08	3.93	4.08	4.27
Gly	0.90	0.96	0.97	1.01
His	0.51	0.46	0.48	0.51
Ile	0.71	0.64	0.74	0.77
Leu	1.93	1.73	1.88	1.94
Lys	1.19	1.08	1.19	1.23
Met	0.20	0.15	0.24	0.16
Phe	0.94	0.84	0.94	0.95
Pro	1.49	1.59	1.55	1.75
Ser	0.85	0.82	0.78	0.86
Thr	0.84	0.75	0.80	0.81
Tyr	0.44	0.48	0.44	0.45
Val	1.08	0.92	1.02	1.08
Essential AA	6.89	6.11	6.81	6.94
Total AA	19.16	18.17	19.17	19.84

[1]Including aspartate plus asparagines.
[2]Including glutamate plus glutamine.

Table 4. Analyzed AA composition of experimental diets (Phase 2, Days 29–56; %, as-fed basis)

Content	Control	*Tenebrio molitor*	*Musca domestica* larvae	*Zophobas morio*
Ala	0.95	1.01	0.98	0.97
Arg	0.95	0.93	0.93	0.90
Asp[1]	1.72	1.64	1.76	1.65
Cys	0.13	0.09	0.12	0.11
Glu[2]	3.68	3.59	3.72	3.57
Gly	0.90	0.96	0.97	1.01
His	0.46	0.44	0.45	0.44
Ile	0.62	0.61	0.59	0.62
Leu	1.82	1.66	1.65	1.65
Lys	1.05	0.92	0.98	0.95
Met	0.14	0.16	0.19	0.16
Phe	0.87	0.79	0.82	0.80
Pro	1.33	1.35	1.31	1.21
Ser	0.73	0.72	0.64	0.66
Thr	0.74	0.68	0.69	0.67
Tyr	0.36	0.43	0.44	0.38
Val	0.96	0.91	0.84	0.88
Essential AA	4.38	4.07	4.11	4.08
Total AA	17.12	16.59	16.73	16.22

[1]Including aspartate plus asparagines.
[2]Including glutamate plus glutamine.

Table 5. Effects of dietary protein from different sources on ileal apparent digestibility (%) of nutrients in early-weaned piglets (Phase 1, Days 1–28)

Item	Control	*Tenebrio molitor*	*Musca domestica* larvae	*Zophobas morio*
CP	87.58 ± 3.87	89.48 ± 5.09	86.53 ± 2.85	87.56 ± 1.14
DM	84.79 ± 3.33	80.11 ± 5.52	81.93 ± 6.90	80.48 ± 1.34
Ala	70.00 ± 15.39	71.25 ± 21.79	77.67 ± 11.59	78.67 ± 12.34
Arg	94.67 ± 1.15	92.50 ± 2.52	94.67 ± 3.79	93.67 ± 1.53
Asp[1]	92.00 ± 2.65	91.00 ± 3.16	90.33 ± 7.09	91.00 ± 1.73
Cys	77.33 ± 4.16	69.50 ± 25.68	85.33 ± 17.62	67.33 ± 24.50
Glu[2]	92.33 ± 2.31	92.25 ± 2.99	93.33 ± 4.51	93.33 ± 0.58
Gly	81.67 ± 6.03	80.25 ± 4.92	80.67 ± 15.04	87.33 ± 2.08
His	88.33 ± 5.13	88.50 ± 3.79	88.33 ± 10.02	90.00 ± 3.61
Ile	90.67 ± 2.89	88.25 ± 2.99	90.33 ± 7.51	91.00 ± 2.65
Leu	90.67 ± 2.89	88.25 ± 3.95	90.67 ± 7.02	91.33 ± 2.89
Lys	92.67 ± 3.06	89.75 ± 2.63	92.00 ± 5.57	91.67 ± 1.53
Met	91.33 ± 2.52	92.50 ± 6.56	91.67 ± 7.09	90.67 ± 5.86
Phe	91.00 ± 2.65	89.00 ± 2.16	89.67 ± 7.64	89.67 ± 2.31
Pro	89.67 ± 7.57	94.00 ± 3.56	94.00 ± 3.61	94.00 ± 1.73
Ser	91.00 ± 4.00	79.75 ± 17.75	88.33 ± 8.39	89.00 ± 2.65
Thr	88.33 ± 4.16	86.25 ± 3.30	85.67 ± 9.87	85.33 ± 2.31
Tyr	86.87 ± 3.06	84.75 ± 3.86	85.00 ± 10.15	86.00 ± 2.31
Val	90.67 ± 3.06	89.00 ± 6.16	88.00 ± 7.94	87.67 ± 3.06

[1]Including aspartate plus asparagines.

[2]Including glutamate plus glutamine.

Table 6. Effects of dietary protein from different sources on ileal apparent digestibility (%) of nutrients in early-weaned piglets (Phase 2, Days 29–56). Values are means (SE); $n = 6$.

Item	Control	*Tenebrio molitor*	*Musca domestica* larvae	*Zophobas morio*
CP	79.60 (6.74)	81.28 (7.27)	79.12 (7.28)	79.12 (7.28)
DM	74.76 (9.66)	75.85 (3.69)	75.96 (6.17)	74.09 (2.69)
Ala	57.50 (19.09)	78.67 (4.93)	62.50 (17.68)	60.33 (11.37)
Arg	82.00 (12.73)	92.00 (3.46)	91.00 (2.83)	78.00 (11.02)
Asp[1]	88.50 (3.54)	91.00 (3.00)	86.50 (0.71)	79.00 (9.54)
Cys	54.50 (14.85)	77.00 (14.80)	80.00 (1.43)	53.00 (23.58)
Glu[2]	93.46 (0.70)	92.67 (3.06)	89.50 (2.12)	82.67 (5.86)
Gly	69.00 (8.49)	70.67 (12.22)	79.00 (5.66)	51.33 (14.43)
His	76.00 (16.97)	88.00 (4.36)	87.50 (6.36)	72.67 (4.51)
Ile	78.5 (14.85)^{ab}	90.00 (3.00)^{a}	85.50 (0.71)^{ab}	75.00 (9.64)^{b}
Leu	83.00 (12.73)	90.67 (2.08)	85.00 (1.41)	74.67 (8.39)
Lys	80.50 (14.14)	89.33 (3.51)	87.50 (2.12)	73.67 (12.86)
Met	75.50 (16.26)^{b}	97.00 (2.00)^{a}	90.50 (2.12)^{a}	75.00 (7.55)^{b}
Phe	79.00 (14.14)	89.67 (3.06)	84.00 (1.41)	75.00 (10.58)
Pro	87.50 (9.19)	89.67 (6.03)	88.50 (3.54)	74.67 (11.02)
Ser	75.00 (18.38)	87.33 (4.93)	81.50 (4.95)	73.00 (13.74)
Thr	82.00 (4.24)	84.33 (5.13)	78.50 (3.54)	67.00 (14.18)
Tyr	64.00 (28.28)	86.33 (4.93)	77.50 (0.71)	62.00 (15.13)
Val	88.00 (1.41)	87.67 (4.04)	81.50 (2.12)	72.33 (11.23)

^{a,b}Means with different superscripts in a row differ ($P < 0.05$).

[1]Including aspartate plus asparagines.

[2]Including glutamate plus glutamine.

according to the method described by Yin et al. (2000).

Statistical Analysis

Data were expressed as the means ± SE. Results were statistically analyzed using 1-way ANOVA (SPSS18.0; SPSS Inc., Chicago, IL). Duncan's multiple range test was used to compare differences among the treatment groups. A *P*-value of less than 0.05 was taken to indicate statistical significance.

RESULTS AND DISCUSSION

Currently, the major sources of protein used in animal feed are fish, soybean, and processed animal protein. Insects contain a high quantity of protein (30–70%) as measured on a dry weight basis. Moreover, as a feed ingredient, insect powder may have favorable conversion efficiency (Veldkamp et al., 2012). However, there were no significant differences between the experimental groups supplemented with dried insect powder and the control group with respect to BW, ADG, and F:G ratio ($P > 0.05$; data not shown) in the present study. No difference in BW was observed between groups at any phase of the experiment, which suggests that dietary insect powder is as efficient as plasma protein powder for growth performance in early-weaned piglets. However, a decrease ($P < 0.05$) in ADFI was measured in piglets fed TM (102 ± 18 vs. 76 ± 18 g) and MDL (102 ± 18 vs. 79 ± 14 g) at 7 d, and an increase ($P < 0.05$) in ADFI was measured in piglets fed ZM between Days 15 and 28 (137 ± 34 vs. 220 ± 49 g) and between Days 29 and 56 (359 ± 42 vs. 532 ± 72 g), when compared with the control group. The early decrease in feed intake in early-weaned piglets might result from the inelastic texture of dietary insect powder, whereas the increase in ADFI between Days 28 and 56 might reflect positive feedback after the adaptation period. The parallel feed conversion between the groups may be due to a lower utilization of insect protein caused by early-weaning stress in the gastrointestinal tract. This hypothesis will need to be validated by further experimental testing.

In modern intensive pork-production systems, piglets are weaned early to optimize whole-herd production efficiency. However, early weaning can often cause stress, lead to growth retardation, and increase morbidity and mortality, in relation to an increased incidence of diarrhea in piglets, and this is associated with negative economic consequences (Kong et al., 2007). Weaning stress may result in intestinal inflammation and dysbacteriosis, which can be reduced by the use of antibacterial compounds. The antibacterial peptides from insects may help to prevent inflammation and mucosal dam-

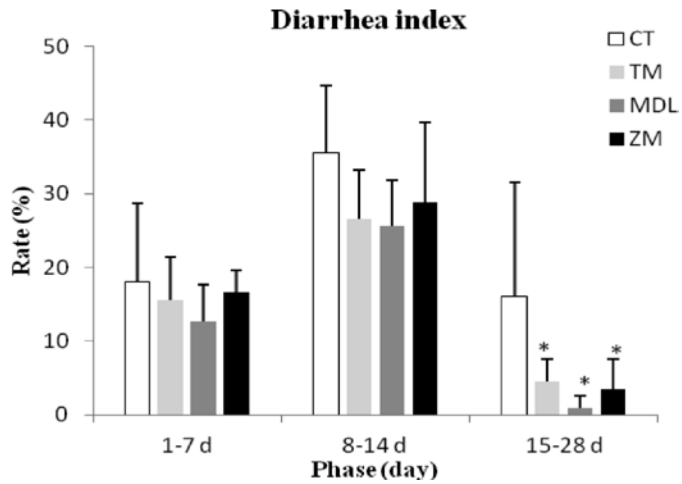

Figure 1. Effects of dietary protein from different sources on the diarrhea rate (%) in early-weaned piglets. Values are means ± SE; $n = 6$. For each phase, means with * significantly differ ($P < 0.05$). CT = control group; TM = *Tenebrio molitor*; MDL = *Musca domestica* larvae; ZM = *Zophobas morio*.

age (Kang et al., 2011). Our results showed that there were no differences in the diarrhea rate in early-weaned piglets with dietary insect powders at the early phase after weaning. Interestingly, however, dietary supplementation with TM, MDL, or ZM powder was associated with a marked decrease in the diarrhea rate at 15 through 28 d (Fig. 1), indicating that insect powder may be an effective functional feed protein source to reduce piglet diarrhea in the late phase of the weaning period.

The measurement of blood biochemical parameters, including some enzymatic activities, metabolites, and hormones, is a sensitive way to estimate the overall body metabolic status (Hodgson and Rose, 2005). The plasma concentrations of TP and ALB indirectly reflect the digestion of protein and the absorption and metabolism of AA. In this study, pigs fed ZM had the lowest plasma concentrations of TP and ALB at 56 d and these values were significantly lower ($P < 0.05$) than those in the control group (Table 7). This result may indicate that pigs fed ZM do not optimally use this protein source. The measurement of plasma urea nitrogen allows the determination of a metabolic end product of protein and AA metabolism. In this study, no difference was found between the experimental and control groups, indicating that the utilization of protein and AA as well as nitrogen deposition were likely similar after supplementation with the insect powders or with the plasma protein powder. As a toxic metabolite when present in excess in the circulation, plasma AMM is kept at a low concentration by conversion to urea through the hepatic urea cycle (Mouille et al., 2004). In this study, the plasma AMM concentration in the control group was significantly greater ($P < 0.05$; Table 7) than those in the other groups with insect powders at Day 28, suggesting that nitrogen metabolism may differ according to the dietary treatment.

To further determine nutrient utilization in the different diets, the AID was tested. The digestibility of CP may be affected by the balance between AA absorption and metabolism (Urbaityte et al., 2009). In this study, there was no significant difference in nutrient AID (including CP, DM, and AA) in Phase 1 compared with the control group ($P > 0.05$; Table 5). As shown in Table 6, AID of Met in all of the groups supplemented with in-

Table 7. Effects of dietary protein from different sources on plasma biochemical parameters in early-weanling piglets. Values are means (SE); $n = 6$

Time	Item[1]	Control	*Tenebrio molitor*	*Musca domestica* larvae	*Zophobas morio*
28 d	ALB, g/L	27.05 (5.45)	23.82 (2.77)	24.68 (5.42)	22.48 (7.03)
	AMM, μmol/L	133.85 (21.18)^a	96.55 (44.36)^b	84.70 (25.28)^b	80.75 (26.26)^b
	TP, g/L	54.32 (12.57)	51.65 (11.56)	43.98 (6.72)	42.80 (12.20)
	UN, mmol/L	4.36 (1.15)	5.88 (2.28)	4.34 (0.62)	3.56 (1.23)
56 d	ALB, g/L	33.25 (5.98)^a	27.82 (3.47)^{ab}	33.73 (6.27)^a	24.87 (5.44)^b
	AMM, μmol/L	135.63 (22.93)	172.35 (77.23)	150.45 (44.15)	147.17 (43.92)
	TP, g/L	60.4 (4.41)^a	57.07 (4.09)^{ab}	62.62 (6.67)^a	52.3 (4.99)^b
	UN, mmol/L	4.30 (0.49)	4.65 (0.82)	4.93 (0.97)	4.95 (1.04)

^{a,b}Means with different superscripts in a row differ ($P < 0.05$).

[1]ALB = albumin; AMM = ammonia; TP = total protein; UN = urea nitrogen.

sect protein was increased ($P < 0.05$) in Phase 2 and no significant changes were found in the other parameters. This revealed that dietary insect powder may be a good source of protein for early-weaned piglets. In addition, the changes in the AID of some AA may be due to differences in the structure and constitution of insect proteins. Further studies will be needed to explore this possibility.

In conclusion, our findings showed that the use of insect powder as a protein source in feed reduced diarrhea rate in early-weaned piglets without affecting growth performance, which indicates that insect powder is a potentially promising protein source for pig production.

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