

Effects of soybean meal processing treatments on growth performance, nutrient digestibility, nitrogen and phosphorus excretion in red swamp crayfish, *Procambarus clarkii*

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Abstract In this study, growth performance, apparent digestibility coefficients, phosphorus and nitrogen excretion were determined in red swamp crayfish (*Procambarus clarkii*) (5.39 ± 0.12 g) for four soybean products: soybean meal (SBM), soybean meal diets supplemented with 1000 IU/kg phytase (SBM + P), extruded soybean meal (ESBM) and fermented soybean meal (FSBM). The results showed that compared with the SBM diet, the crayfish fed the SBM + P and FSBM diets showed significantly higher specific growth rate (SGR) and lower feed conversion ratio (FCR) ($P < 0.05$). The highest and lowest dry matter (DM) digestibilities were observed in SBM + P and ESBM diets, respectively ($P < 0.05$). Differences in crude protein (CP) and gross energy (GE) followed differences in DM digestibility. SBM + P had the highest phosphorus digestibility, and ESBM had the lowest. The highest crude lipid (CL) digestibility coefficient was observed in FSBM, followed by SBM + P, and the lowest in ESBM ($P < 0.05$), which was similar to SBM. And the ESBM group had the highest phosphorus content in sediments ($P < 0.05$); while the highest nitrogen content was observed in SBM group, which was significantly higher than SBM + P group ($P < 0.05$). The water phosphorus contents in SBM and ESBM groups were significant higher than SBM + P group at 48 h ($P < 0.05$), but there were no significant differences among the water nitrogen content of all groups ($P > 0.05$).

Keywords *Procambarus clarkii* · Soybean products · Growth performance · Nutrient digestibility · Phosphorus · Nitrogen

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Introduction

Fish meal (FM) has been the most important feedstuff used as a source of protein in aquaculture feeds because of its essential amino acid composition and palatability (Amaya et al. 2007). However, the increasing price and the shortage supply of FM severely restrict the development of aquaculture (Tacon and Dominy 1999). Therefore, the current trend is to decrease fish meal in aquafeeds (Lemos et al. 2009) and find alternative dietary protein sources (Goytortua-Bores et al. 2006; Cruz-Suárez et al. 2009; Yang et al. 2009), which is more critical in China where small amounts of high quality FM are produced. Compared with other plant protein sources, soybean meal (SBM) has been the most promising and frequently alternate protein source for many agriculture animals, due to its reasonable price, steady supply, relatively high protein content and well-balanced amino acid profile (Storebakken et al. 2000). The use of SBM as a dietary protein source has been examined for many important fish species, such as sharp-snout sea bream *Diplodus puntazzo* (Rondán et al. 2004), Asian sea bass *Lates calcarifer* (Tantikitti et al. 2005) and gilt-head sea bream *Sparus aurata* (Venou et al. 2006; Bonaldo et al. 2008). However, the presence of anti-nutritional factors, non-available phosphorous, relative low levels of nutrients digestibility and palatability problems may limit high inclusion levels of soybean meal in diets of aquatic animals (Hardy 1996; Gatlin et al. 2007; Dalsgaard et al. 2009). Some reports indicate that the enzyme treatment or extrusion, ferment processing can decrease the content of flatulence-producing oligosaccharides and allergenic proteins and increase the digestibility of SBM (Biswas et al. 2007; Feng et al. 2007; Dehkordi and Vali 2014).

In inland China, the red swamp crayfish (*Procambarus clarkii*) has recently become one of the most important commercially cultivated crustaceans in China, especially in Jiangsu Province, with gross output value more than 200 million US dollars in 2009 (Ding et al. 2012). Increased annual production through intensification of production is important for continued growth of the industry, which increase the cost of production and water pollution problems. However, nutritional information on this species is limited and no data are available on the dietary utilization of SBM. Hence, the purpose of this experiment was to investigate four soybean meal ingredients (soybean meal, soybean meal diets supplemented with 1000 IU/kg phytase, extruded soybean meal and fermented soybean meal) supplementation in practical diets on growth, apparent digestibility coefficients, phosphorus and nitrogen excretion of *P. clarkia*. This result could be useful for formulating low-cost and low-polluting plant-based diets for crayfish.

Materials and methods

Diet preparation

Four diets were produced at the Wuxi Freshwater Fisheries Research Center, Jiangsu, China. The diets were formulated to contain approximately 27.20 % crude protein and 6.49 % crude lipid (Table 1) according to the previous research (Xu et al. 2013). Yttrium oxide (Y_2O_3) was used as the inert marker at a concentration of 0.1 % in diet.

The dietary treatments were as follows:

- SBM diet: Soybean meal as the main source of protein.
- SBM + P diet: SBM diet with 1000 IU/kg phytase (BASF China Ltd., Shanghai, China).

Table 1 Formulation and proximate chemical composition of diets (% dry matter)

Ingredients	SBM diet	SBM + P diet	ESBM diet	FSBM diet
Fish meal	70.00	70.00	70.00	70.00
Soybean meal	510.00	510.00	210.00	210.00
Phytase (IU/kg)		1000		
Extruded soybean meal			300.00	
Fermented soybean meal				300.00
Rapeseed meal	56.00	56.00	56.00	56.00
Cottonseed meal	56.00	56.00	56.00	56.00
Flour	217.00	217.00	217.00	217.00
Soybean oil	14.00	14.00	14.00	14.00
Fish oil	14.00	14.00	14.00	14.00
Attapulgate	10.50	10.50	10.50	10.50
Salt	2.10	2.10	2.10	2.10
Ecdysone premix	1.05	1.05	1.05	1.05
Shrimp shell meal	21.00	21.00	21.00	21.00
Calcium biphosphate	17.15	17.15	17.15	17.15
Carboxymethyl cellulose	3.50	3.50	3.50	3.50
Premix ^a	7.00	7.00	7.00	7.00
Y ₂ O ₃	1.00	1.00	1.00	1.00
Chemical composition (% dry matter)				
Crude protein	28.91	28.89	27.86	30.10
Crude lipid	6.33	6.34	6.04	6.72
Ash	7.12	7.11	7.23	7.08
Gross energy (kJ/g)	18.34	18.37	19.35	19.12

^a Premix (mg or g kg⁻¹ diet): CuSO₄·5H₂O, 2 g; FeSO₄·7H₂O, 25 g; ZnSO₄·7H₂O, 22 g; MnSO₄·4H₂O, 7 g; CoCl₂·6H₂O, 0.1 g; Na₂SeO₃, 0.04 g; KI, 0.026 g. Vitamin E, 150 IU; vitamin K, 50 mg; vitamin B₁, 80 mg; vitamin B₂, 50 mg; vitamin B₆, 50 mg; vitamin B₁₂, 0.02 mg; niacin acid, 150 mg; pantothenic acid, 150 mg; biotin, 1 mg; folic acid, 10 mg; inositol, 300 mg; vitamin C, 300 mg; vitamin A, 10,000 IU; vitamin D₃, 2000 IU

ESBM diet: 30 % of soybean meal replaced by extruded soybean meal (Bunge (Nanjing) Agribusiness and Food Co. Ltd., Jiangsu Province, China).

FSBM diet: 30 % of soybean meal replaced by fermented soybean meal (Zhejiang Cofine Biotech. Inc. Ltd., Zhejiang Province, China).

All feed ingredients were obtained from commercial sources and subjected to chemical analysis (Table 2). Various feedstuffs were separately ground, screened through 60 mesh size sieve and mixed for 15 min in a Kitchen Aid mixer. Y₂O₃ was dissolved in 20 ml of distilled water and sprayed with an atomizer on the mash during mixing. Then fish oil and soybean oil were thoroughly mixed through the ingredient mixture, and the water (15–20 %) was added and mixed for 15 min. The dough was then pelleted into diameter of 2 mm granular feed using a small feed machine and dried in a ventilated oven at 40 °C for 12 h. All diets were stored at 4 °C until use.

Table 2 Proximate composition of test ingredients ($n = 3$)

	Ingredients ¹			
	SBM	SBM + P	ESBM	FSBM
Dry matter, DM (%)	89.20	89.38	89.23	88.44
Crude protein (%DM)	43.96	43.68	42.99	47.76
Crude lipid (%DM)	1.05	1.06	1.25	1.22
Ash (%DM)	6.81	6.67	7.66	7.10
Gross energy (Mj·kg ⁻¹ DM)	18.22	18.83	14.89	18.41
Phosphorus (%DM)	0.65	0.65	1.02	0.82

Mean ($n = 3$ samples), ¹soybean meal (SBM), Tong Wei Co. Ltd., Wuxi branch, Jiangsu Province, China; phytase, BASF China Ltd., Shanghai, China; extruded soybean meal (ESBM), Bunge (Nanjing) Agribusiness and Food Co. Ltd., Jiangsu Province, China; fermented soybean meal (FSBM), Zhejiang Cofine Biotech. Inc. Ltd., Zhejiang Province, China

Experimental animals and culture conditions

The experimental crayfish were obtained from Lukou fish farm of Freshwater Fisheries Research Institute of Jiangsu Province, China. The crayfish were acclimated to the experimental conditions for two weeks in a 25,000-L PVC tank and fed with the reference diet (RF) three times daily to satiation. Thereafter, 12 crayfish (initial mean weight, 5.39 ± 0.12 g) were randomly distributed into per indoor rectangular tank ($1.0 \text{ m} \times 0.4 \text{ m} \times 0.4 \text{ m}$, height of water 0.2 m) with a flow-through system. A total of four PVC tubes of 15 cm length were placed in each tank to reduce the aggressive interaction among crayfish. During the experiment, triplicate groups of crayfish were fed twice daily at satiation level at 0800 and 1600 h. Four diets were randomly assigned to twelve tanks. The daily feed supplied was recorded, and uneaten feed was removed from the tanks 1 h after feeding in order to avoid the contamination of feces with uneaten feed. Crayfish were acclimated to the experimental diets containing Y_2O_3 for 7 days before initial collection of feces, and after a 7-day feeding period, immediate pipetting (a Pasteur pipet) was used for feces collection (Goytortua-Bores et al. 2006). Fecal matter was continually collected between 0900 and 1900 h the next day. The feces were siphoned into a bucket and then transferred with a pipette into glass dish, and collected fecal matter was rinsed very gently in distilled water for a few seconds to remove other materials (e.g., dirt particles), then oven-dried (50°C) and kept frozen at -20°C until analyzed. Successive fecal samples collected from the same tank were bulked together in the collection valve bag until a sample of at least 5 g dry weight of feces had been collected. This was sufficient for the intended chemical analyses.

During the experimental period, tanks were cleaned daily at 0700 and 1500 h before feeding and the water source is from underground. Aeration was also provided to maintain enough dissolved oxygen (DO). During the rearing period, daily water exchange was $\sim 80\%$ in all tanks, water temperature was 28.7 ± 3.6 (above 30°C for one week), the water quality was as follows: pH 6.9 ± 0.3 , DO 7.54 ± 0.07 , $\text{NH}_3 < 0.048 \text{ mg/L}$, $\text{H}_2\text{S} < 0.015 \text{ mg/L}$, and crayfish were exposed to alternating 12-h light and dark periods. The exuvial and dead crayfish were checked daily.

Nitrogen and phosphorus excretion experiment

At the end of the rearing experiment, a subsample of crayfish with same size from four groups (3 tanks/group, $N = 8$ crayfish/tank) was selected for nitrogen and phosphorus excretion experiment for 2 days under the same rearing condition above. According to the method described by Yang et al. (2011), 20 mL of water was sampled at 0, 6, 12, 24 and 48 h after excretion experiment. The water was stored at 4 °C after extraction filter for the total nitrogen and phosphorus analyses. Moreover, the sediments were collected from each tank at 48 h after excretion experiment, and then the samples were oven-dried (50 °C) and stored in a sealed bag at 4 °C until analyzed. During the experiment, crayfish were fed twice daily at 0800 and 1600 h, the water wasn't changed, and the uneaten feed wasn't removed.

Analytical methods and calculation formula

Specific growth rate, feed conversion ratio and survival were calculated follows:

$$\text{Specific growth rate (SGR, \% day}^{-1}\text{)} = 100 \times [\text{Ln (final body weight)} - \text{Ln (initial body weight)}] / \text{test days}$$

$$\text{Feed conversion ratio (FCR)} = \text{total feed consumption} / \text{total weight gain}$$

$$\text{Survival (\%)} = 100 \times (\text{final amount of fish}) / (\text{initial amount of fish})$$

Feed ingredients, experimental diets and fecal samples (from each tank) were analyzed in triplicate by the standard methods of AOAC (1995). Samples were dried to a constant weight at 105 °C for the determination of dry matter; ash was determined by incineration in a muffle furnace at 550 °C for 24 h; crude protein (% nitrogen $\times 6.25$) by the Kjeldahl system method using a BUCHI nitrogen determinator (model K-360, BUCHI Corporation, Flawil, Sweden); crude lipid by ether extraction using Soxhlet; gross energy by an fully automatic calorimeter (model TYHW-V, Hebi Tianyu Instrument And Meter Manufacturing Co. Ltd., Hebi, China). Yttrium oxide and phosphorus were analyzed using an inductively coupled plasma-atomic emission spectrophotometer (model Prodigy, Leeman Labs Inc., New Hampshire, USA).

The ADCs for the nutrients and energy of the test and reference diets were calculated using the following formula (Cho and Kaushik 1990):

$$\text{ADC of nutrient (\%)} = 100 \times [1 - (F/D) \times D_Y/F_Y],$$

where F = % nutrient or gross energy in feces; D = % nutrient or gross energy in diet; D_Y = % Y_2O_3 in diet; and F_Y = % Y_2O_3 in feces.

The ADCs for ingredients were calculated using the following formula (Cho et al. 1982):

$$D_i = (D_T - rD_R) / (1 - r);$$

$$r = (0.3 \times W_T) / (W_T \times 0.3 + W_R \times 0.7)$$

where D_i = apparent digestibility of nutrient or gross energy in the test ingredient; D_T = the ADCs of nutrient or gross energy concentration in test diet; D_R = the ADCs of nutrient or gross energy concentration in the reference diet; W_T = the nutrient or gross

energy concentration in the test diet; W_R = the nutrient or gross energy concentration in the reference diet. In all cases, the average value of each specific reference diet was used to calculate ingredient ADCs.

The levels of phosphorus and nitrogen in water were measured in water quality analyzer San⁺⁺ (Skalar, Holland), and the levels of phosphorus and nitrogen in sediment were measured in spectrophotometer VIS-723 (Beijing Beifen-Ruili Analytical Instrument (Group) Co. Ltd., China) and azotometer KDN-04AA (Shanghai Jiading Cereal And Oil Instrument Co. Ltd., China).

Statistical analysis

All data were subjected to one-way analyses of variance (ANOVA) followed by Duncan's multiple range test at a significant level of $P < 0.05$, and the data were presented as mean $\pm$ SE of three replicate groups. All statistical analyses were carried out using the SPSS 16.0 for Windows (SPSS, Michigan Avenue, Chicago, IL, USA).

Results

Growth performance

At the end of the trial, final weight in crayfish fed the SBM did not significantly differ ($P > 0.05$) from those fed with the FSBM, but was significantly lower than the crayfish fed with SBM + P and significantly higher than ESBM ($P < 0.05$) (Table 3). Crayfish fed with SBM and ESBM had significantly lower specific growth rate (SGR) and higher feed conversion ratio (FCR) than other treatments ($P < 0.05$). However, there was no significant difference in survival among all groups ($P > 0.05$).

Nutrient digestibility

The apparent digestibility coefficients (ADCs) of dry matter (DM) were observed to be the highest in SBM + P and the lowest in ESBM ($P < 0.05$) (Table 4). Differences in crude protein (CP) and gross energy (GE) followed differences in DM digestibility. SBM + P had the highest phosphorus digestibility, and ESBM had the lowest. The highest crude lipid digestibility was observed in FSBM, which was similar to SBM + P, and the lowest was observed in ESBM ($P < 0.05$).

Table 3 Effects of soybean meal processing treatments on growth performance of red swamp crayfish

Diets	Initial body weight (g)	Final body weight (g)	SGR (%/d)	FCR	Survival (%)
SBM	5.50 $\pm$ 0.08	13.17 $\pm$ 1.01 ^b	2.49 $\pm$ 0.10 ^b	1.71 $\pm$ 0.11 ^a	91.67 $\pm$ 1.50
SBM + P	5.47 $\pm$ 0.09	14.93 $\pm$ 0.81 ^a	2.87 $\pm$ 0.07 ^a	1.54 $\pm$ 0.12 ^b	91.67 $\pm$ 1.10
ESBM	5.19 $\pm$ 0.08	11.26 $\pm$ 0.35 ^c	2.21 $\pm$ 0.10 ^c	1.92 $\pm$ 0.10 ^a	91.67 $\pm$ 1.66
FSBM	5.31 $\pm$ 0.05	13.82 $\pm$ 1.03 ^{ab}	2.73 $\pm$ 0.09 ^a	1.54 $\pm$ 0.09 ^b	83.33 $\pm$ 1.90

Values as mean $\pm$ SD of three replicate tanks and values within the same column with different superscript letters are significantly different (Duncan's multiple range test, $P < 0.05$)

Table 4 Effect of soybean meal processing treatments on ADCs (%) for dry matter, crude protein, crude lipid, energy and phosphorus of red swamp crayfish

Diets	Dry matter	Crude protein	Crude lipid	Gross energy	Phosphorus
SBM	71.4 ± 1.88 ^b	82.8 ± 1.63 ^b	79.3 ± 2.40 ^b	83.9 ± 1.51 ^b	54.9 ± 1.50 ^b
SBM + P	79.6 ± 2.29 ^a	90.1 ± 1.88 ^a	84.1 ± 5.75 ^{ab}	92.2 ± 5.91 ^a	65.8 ± 1.63 ^a
ESBM	60.6 ± 2.68 ^c	76.0 ± 2.84 ^c	77.7 ± 3.41 ^b	76.7 ± 1.34 ^c	52.6 ± 2.81 ^b
FSBM	70.1 ± 3.17 ^b	82.5 ± 2.32 ^b	87.0 ± 2.55 ^a	82.1 ± 3.03 ^b	61.4 ± 2.71 ^a

Values as mean ± SD of three replicate tanks and values within the same column with different superscript letters are significantly different (Duncan's multiple range test, $P < 0.05$)

The content of nitrogen and phosphorus in sediments

The results showed that the ESBM group had the highest phosphorus content in sediments ($P < 0.05$) (Table 5) and there was no significant difference among SBM, SBM + P and FSBM groups ($P > 0.05$) (Table 5). And the nitrogen content in sediments was observed to be the highest in SBM and the lowest in SBM + P ($P < 0.05$).

The content of nitrogen and phosphorus in water

As shown in Fig. 1, the water nitrogen and phosphorus content of all groups showed an increasing tendency during nitrogen and phosphorus excretion experiment. There were no significant differences among the nitrogen content of all groups ($P > 0.05$). For phosphorus, the phosphorus content of SBM + P group was significantly lower than SBM and ESBM groups at 48 h ($P < 0.05$) while the difference among all groups was not significant at 0, 6, 12 and 24 h ($P > 0.05$).

Discussion

Effects of soybean meal processing treatments on growth performance in red swamp crayfish

The incorporation of phytase into fish aquatic diets improves overall performance, nutritional efficiency and protein digestibility, while reducing P content within several fish species (Sugiura et al. 2001; Yan and Reigh 2002; Vielma et al. 2004; Cao et al. 2008),

Table 5 Effect of soybean meal processing treatments on phosphorus and nitrogen content in sediments of red swamp crayfish

Diets	Total phosphorus %	Total nitrogen %
SBM	1.43 ± 0.02 ^b	7.77 ± 0.23 ^a
SBM + P	1.43 ± 0.01 ^b	6.51 ± 0.01 ^b
ESBM	1.71 ± 0.05 ^a	7.12 ± 0.32 ^{ab}
FSBM	1.52 ± 0.01 ^b	7.23 ± 0.10 ^{ab}

Values as mean ± SE of three replicate tanks and values within the same column with different superscript letters are significantly different (Duncan's multiple range test, $P < 0.05$)

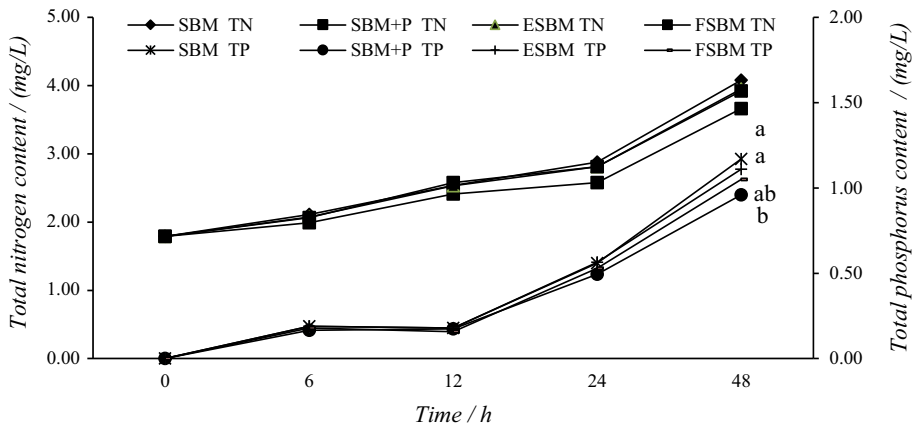


Fig. 1 Effect of soybean meal processing treatments on content of nitrogen and phosphorus in water of red swamp crayfish. *Notes* Values as mean $\pm$ SD of three replicate tanks and values within the same time with different superscript letters are significantly different (Duncan's multiple range test, $P < 0.05$)

especially in plant-based diets. This agrees with the present study, which indicated crayfish fed the soybean meal-based diet supplemented with 1000 FIU/kg phytase (SBM + P diet) had the highest specific growth rate (SGR) and the lowest feed conversion ratio (FCR). Similarly, Suprayudi et al. (2012) reported that phytase level of 500 IU supports the best growth performance of juvenile white shrimp *Litopenaeus vannamei*. The results obtained in the present study were also similar to previous findings in other aquatic animals (Li et al. 2004; Biswas et al. 2007; Cao et al. 2008). These studies indicated that dietary phytase could improve the growth performance and feed utilization of crayfish. The effect of phytase may be related to phytate, which is one of the anti-nutritional factors of plant proteins, and phytase can be added to plant-based diets to hydrolyze non-digestible phytate and improve growth performance (Sugiura et al. 2001). In contrast, the phytase supplementation did not affect growth performance in other research, i.e., Civera and Guillaume (1989) for juvenile *Penaeus japonicus*, Biswas et al. (2007) for juvenile *Penaeus monodon*. The discrepancy in above findings may be associated with differences in their diet composition and also with different rearing conditions (Baruah et al. 2007).

In our study, the fermented soybean meal (FSBM) diet could also increase the SGR and lower FCR of red swamp crayfish ($P < 0.05$). This growth improvement may be attributed mostly to the improvement in the nutritional value and the elimination of anti-nutritional factors when soybeans are fermented (Hong et al. 2004). Sharawy et al. (2016) reported that the process of fermentation has advantage for increasing crude protein, lipid and decreasing anti-nutrients such as phytic acid in India prawn shrimp. Khan and Ghosh (2012) reported that the biological methods such as solid-state fermentation of SBM increase nutrient bioavailability as well as improve growth performance because of the action of enzymes produced by the microorganisms. This is similar to the study of Shiu et al. (2013) for white shrimp, *Litopenaeus vannamei*.

However, there was no difference in SGR and FCR between the SBM and extruded soybean meal diet (ESBM diet) groups in this experiment. Similar results were reported previously (Annexstad et al. 1987; Oliva-Teles et al. 1994). The reasons may be that soybean meals produced by extruding–expelling have poor functional properties due to heat denaturation of the proteins, which limits their utilization in foods (Wang et al. 2004).

In contrast, several studies observed that ESBM was more digestible than conventional soybean meal and could be successfully used in diets of pigs (Woodworth et al. 2001) and Japanese quails (Dehkordi and Vali 2014) and benefits of extrusion were attributed to reductions in anti-nutrients, including phytic acid (Allan and Booth 2004). The discrepancy was mainly due to the differences among species.

Effects of soybean meal processing treatments on nutrient digestibility and phosphorus and nitrogen excretion of red swamp crayfish

In terms of anti-nutritional factors, phytate can also integrate with cation groups on protein, amino acids, starch and lipids in feedstuff reducing the digestibility of these nutrients in fish. Moreover, since a low digestibility of phytate by fish, most of the phytate-P ends up being excreted into the water and may cause algal bloom pollution (Baruah et al. 2004). In the present study, the ADC of DM, CP, GE and phosphorus was observed to be the highest in SBM + P; moreover, the levels of nitrogen and phosphorus in sediment and water were observed to be the lowest in SBM + P. In general, the increased nutrient availability and reduction in nitrogen and phosphorus content in the water and sediment could be another explanation for the improved growth performance in SBM + P group. Ricque-Marie et al. (2004) reported that the phytase improved dry matter and protein digestibility to shrimp *Litopenaeus vannamei*. Suprayudi et al. (2012) reported that the phytase addition improved the digestibility of protein and phosphorus of white shrimp *Litopenaeus vannamei*. Improvement in nutrient digestibility by phytase supplementation may be attributed to the effectiveness of phytase on reducing either an anti-nutritional factor or adverse consequences of phytate from soybean meal (Liu 1997), and activity of phytase to dephosphorylate the phytic acid and phytate phosphorus to increase the phosphorus availability (Storebakken et al. 1998). However, a few studies have been published on the contrasting results (Papatryphon et al. 1999; Riche et al. 2001). The probable reason for the neutral and/or negative interaction of phytase and digestibility is that removal of phytate may increase the efficiency of other anti-nutritional factors (Cao et al. 2007). More research is needed to obtain a better insight into the mechanisms for the phytase–protein interaction and nutrient availability.

It is assumed that the anti-nutritional factors were partly destroyed during the fermentation, so the fermentation of soybean meal was found to be able to enhance nutrient digestibility and phosphorus availability (Kiers et al. 2000; Kader et al. 2012; Kim et al. 2010). However, in our study, there were no significant differences in the digestibility of DM, CP, GE and the nitrogen and phosphorus excretion between SBM and FSBM groups by red swamp crayfish. This seemed to be related to an increased dietary phytic acid (Zhou et al. 2011), and also probably due to the incomplete destruction of the ANFs, which could reduce the digestible energy in higher inclusion FSBM diet (Azarm and Lee 2014). Similarly, the ESBM was not advantageous compared with SBM on digestibility and water quality for crayfish in this experiment. Yuan et al. (2010) pointed out that there was no significant difference in apparent DM, crude lipid (CL) and GE digestibility between ESBM and SBM, and perhaps the effects of protein denaturation during processing could explain the above results.

In summary, among enzyme treatment, extrusion and ferment processing of soybean meal, the supplementation of 1000 IU/kg phytase to the SBM diet is the most effective treatment to improve growth responses, nutrition digestibility and water quality of red swamp crayfish. This should be aided in the formulation of more accurate, cost-effective and economical diets for red swamp crayfish.

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