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Replacing Fishmeal With Palm Kernel Meal In Formulated Feed For The Pacific White Shrimp (*Litopenaeus Vannamei*)

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Abstract

Utilisation of plant proteins to replace fishmeal in shrimp feeds has become an important consideration because fishmeal is becoming more expensive due to increasing demand worldwide. Palm kernel meal (PKM) is the by-product of palm kernel oil extraction and its potential use to substitute fishmeal in the Pacific white shrimp (*Litopenaeus vannamei*) diet was evaluated by conducting a 90-day feeding trial. Shrimp juveniles with an initial average weight of 0.5 g, protein content of 10.74±0.70% were randomly distributed into five treatments in triplicates. Four isonitrogenous (approximately 35% protein) diets were formulated to contain 0% (D0), 25% (D25), 50% (D50) and 75% (D75) of PKM replacement and a commercial feed served as control treatment (Control). Results from this study revealed that shrimp fed D25 were comparable with those fed with Control as there was no significant difference ($p>0.05$) in weight gain and specific growth rate (SGR) between the groups. However, PKM inclusions above 50% showed detrimental effects on the growth performance. The highest total protein percent was observed in shrimp tissues fed with D25 (67.59±0.87%) and D75 showed the lowest protein among the treatments (57.4±0.63%) ($p<0.05$). Total lipid content was observed high in shrimp fed with Control (4.33±2.96%) followed by diet D25 (4.32±0.67%). The lowest lipid content was observed in shrimp fed diet D75 (2.03±0.20%). However, there was no significant difference in lipid values among all treatments ($p>0.05$). Shrimp fed with the control treatment contained 16.04±0.03% of carbohydrate and the lowest was found in shrimp fed with D25 (14.67±0.07%) at $p>0.05$. When PKM is utilised to replace FM, a limit of 25% level should be recommended.

Keywords: *Elaeis guineensis*, fishmeal, *Litopenaeus vannamei*, palm kernel meal, replacement

INTRODUCTION

The Pacific white shrimp, *Litopenaeus vannamei*, is native to the Pacific coast of central and South America (Briggs et al., 2005). *L. vannamei* is known for its high growth rate, adaptation to numbers of culture systems, and high market value. This white shrimp species has become one of the most important crustacean species for aquaculture production in Malaysia since its first introduction in 2002 (Kua *et al.*, 2018). The production is increasing from time to time and these shrimps have displaced the black tiger shrimp (*Penaeus monodon*) (Liao and Chien, 2011). Fishmeal is the main ingredient in formulated feeds for cultured shrimps due to its high protein content, balanced amount of amino and fatty acids, vitamins, minerals and palatability (Suárez *et al.*, 2009). However, the price of fishmeal is rising enormously throughout the year considering the demand is more likely higher than the production of fishmeal (Olsen and Hasan, 2012). Shrimp consumption has expected to increase continuously and it is important to develop other cost-effective protein sources to reduce the feed cost and to sustain shrimp industry. Providing shrimp with satisfied levels of nutrition is the fundamental part in feed formulation because maintaining and enhancing the shrimp growth and performance leans on optimal nutrition (Cuzon, 1989; Pratoomyot *et al.*, 2010; Molina-Poveda *et al.*, 2013). Palm

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kernel meal (PKM) is a common by-product from palm kernel oil extraction process in the palm oil industry. PKM is actually the kernel of palm fruits that has been pressed. The common species of palm fruit in Malaysia is *Elaeis guineensis* or known as the African palm oil originating from West Africa (Awalludin *et al*., 2015). Many studies have been done to recycle palm oil residues including the production of palm kernel loose powder or PKM and used to feed animals, both in poultry and aquaculture industries (Agunbiade *et al*., 1999; El-Sayed, 1999; Ng *et al*., 2002; Perez *et al*., 2000; Alimon, 2004; Ezieshi and Olomu, 2008; Hem *et al*., 2008; Iluyemi *et al*., 2010).

PKM shows a potential alternative protein source in poultry and aquaculture feeds other than fishmeal due to its high nutritional values such as carbohydrate and protein (Ng, 2003; Alimon, 2004). The use of PKM has been assessed in the black tiger shrimp, *Penaeus monodon* (Rajaram *et al*., 2010), giant freshwater prawn, *Macrobrachium rosenbergii* (Kader *et al*., 2018), hybrid red tilapia (Ng and Chong, 2002), nile tilapia (Obirikorang *et al.*, 2015) and the common carp, *Cyprinus carpio L.* (Resan and Obaydi, 2019). Replacement of fishmeal with PKM has its own suitable amount which at a certain level of replacement will defect the growth of cultured organisms (Iluyemi *et al*., 2010; Richard *et al*., 2011). Succeesful replacement of fishmeal with PKM will reduce the operating cost because major expenditure is spent on feeds (Hasan *et al*., 2012). To date, there are only a few studies describing the potential of PKM to substitute fishmeal in aquaculture feeds. Therefore, this study was conducted to find the suitable level of fishmeal replacement with PKM in formulating feeds for the Pacific white shrimp.

MATERIAL AND METHODS

Experimental design and sampling procedure

L. vannamei juveniles with an average weight of 0.5±0.03 g per individual were used in this study. These juveniles were obtained from the Fisheries Research Institute, Pulau Sayak, Kedah, Malaysia. The juveniles were acclimatised for seven days to the new conditions in the laboratory. During the acclimatisation period, they were fed with Cargill™ commercial pellets (≈35% protein) for marine shrimp starter at 7% of their biomass. At the beginning of the feeding trial session, the juveniles were placed in black polyethylene tanks filled with approximately 120 L of saltwater. Each tank contained fifty juveniles with a stocking density of two individuals per litre, which were maintained in a static water system with a 50% weekly water exchange.

A total of twenty tanks were used with four replication treatments for each diet. The water temperature in all tanks was maintained at 24±0.5°C, pH at 7.0 to 8.5 and the salinity was kept at 20±0.5 ppt during the twelve weeks period. Other water quality parameters were also observed during the culture period where ammonia, nitrite and nitrate levels were within 0.0-1.0 mg/L, 0.0-2.00 mg/L and 0.0-6.0 mg/L levels, respectively. Both physical and chemical parameters for water quality were measured once a week. Sampling for growth determination was carried out biweekly. An analytical balance (Shimadzu ELB2000) was used to record the wet weight of the juveniles where the shrimps were placed in a beaker containing saltwater. During the sampling, twenty samples from each tank were weighed individually. Growth performance is expressed as wet weight, final weight gain (FWG), specific growth rate (SGR), daily weight gain (DWG) and survival (%).

Feeding and feed formulation

Four isonitrogenous (protein at 35%) diets were formulated by replacing fishmeal with PKM at different levels (0%, 25%, 50%, and 75%). Commercial shrimp feed served as the control treatment. The PKM was obtained from FELDA Palm Kernel Crushing Factory, Pandamaran, Klang, Malaysia. Other ingredients including fishmeal, wheat bran, wheat flour, vitamin, minerals and binder were obtained locally. All the dry ingredients were ground and sieved for finest grained output. Then, all the fine textures were weighed to the measurements of 1 kg formulated diets as stated in Table 1. Then, the mixture was blended to homogenous using a Kitchen Aid™ household mixer. The mixture was hydrated with water as cohesive properties and then was extruded (Kitchen Aid™) into “spaghetti-like” strands using a 2 mm die. The finishing strands were dried in an oven at 60°C for six hours. After drying, the strands were cut into approximately 0.2 mm long pellets. The pellets were kept in plastic containers and stored in room temperature.

Table 1. Feed formulation (g kg^{-1}) and proximate composition (%) of the experimental diets for *Litopenaeus vannamei*. No significant differences with the same letter within a row (p>0.05).

Feed ingredients (g kg^{-1})	Control*	D0	D25	D50	D75
Fishmeal (57% protein)		980.0	735.0	490.0	245.0
Palm kernel meal (18% protein)		-	245.0	490.0	735.0
Wheat flour (11% protein)		10.0	10.0	10.0	10.0
Wheat bran (15% protein)		10.0	10.0	10.0	10.0
Binder		1.5	1.5	1.5	1.5
De cal phosphate		1.5	1.5	1.5	1.5
Vitamin premix		3.0	3.0	3.0	3.0
Minerals		1.5	1.5	1.5	1.5
Proximate composition (%)					
Protein	35.33±0.15	34.97±0.05	35.21±0.43	34.77±0.08	34.78±0.31
Lipid	9.67±0.16^a	6.97±0.27^b	5.39±0.17^c	4.69±0.30^d	5.81±0.25^e
Carbohydrate	32.00±0.38^a	24.00±0.40^b	32.00±0.18^a	33.00±0.48^a	33.00±0.64^a
Moisture	5.67±0.09^a	5.56±0.13^a	4.70±0.08^b	4.16±0.07^c	3.90±0.07^d
Ash	12.24±0.28^a	22.73±0.79^b	14.62±0.62^c	12.12±0.12^a	10.30±0.31^d

*Marine shrimp feed from Cargill™ Malaysia

Proximate analysis for experimental diets and shrimp flesh

The juveniles were deprived of feed for 24 hours prior to analysis to remove unnecessary body composition that might affect the results of proximate analysis (Zhang *et al*., 2007). Fifty individuals were collected from the initial stock and all individuals were collected at the end of the feeding trial and peeled. The shrimp tissues were kept frozen at -20°C until further analysis. Proximate content was also determined for the experimental diets. All analyses were performed in triplicate following the standard methods (AOAC, 2005). Moisture content was determined by drying the samples in an oven for 24 hours at 60°C. The dried samples were burned in a furnace at 600°C for 2 hours. The burned samples were cooled to room temperature in a desiccator and the weight differences were determined as ash content. Analyses of protein were conducted following the Kjeldahl method using the K-425 digestion block and the K-350 distillation system

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(Buchi, Switzerland). Lipids were extracted using the modified Bligh and Dyer method (1959). Total carbohydrate content was estimated by the difference between 100 and the sum of protein, lipid, and ash contents (FAO, 2003).

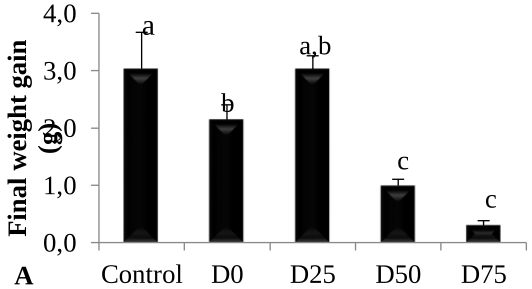
Statistical analyses

Data on the growth parameters and proximate analysis (both diets and shrimp tissues) were analysed with parametric statistics after all assumptions are met and transformations undertaken, when appropriate. The proportions of growth parameters, survival rates and proximate content were transformed using the arcsine square root transformation before being subjected to one-way analysis of variances (ANOVA). Tukey's HSD Post Hoc tests at $p<0.05$ were conducted to determine the differences between the means of all treatments.

RESULTS AND DISCUSSION

Growth performance of shrimp juveniles with treatment diets

In general, the growth performance of shrimps after the 90-day feeding trial showed that the final weight gain (FWG) was greatly reduced corresponded to fishmeal replacement as shown in Figure 1A. At the end of the feeding trial, *L. vannamei* juveniles that fed on D25 and Control had the furthermost increment of weight (3.23±0.23 g individual^{-1} and 3.03±0.63 g individual^{-1}, respectively). There was a significant difference in FWG of juveniles after feeding trial ($p<0.05$). The weight gain in juveniles decreased gradually with the increase in replacement levels of PKM in the treatment feeds. It shows that FWG of shrimp fed with D75 illustrated the lowest result among other treatments (0.30±0.08 g individual^{-1}). It is also noted that FWG of juveniles fed with Control, D0, and D25 showed no significant difference (Tukey's tests, $p>0.05$). The fishmeal replacement with PKM was found affecting the specific growth rate (SGR) of *L. vannamei* juveniles significantly. Figure 1B shows clearly that juveniles fed on D25 had the highest SGR (2.37±0.24%) compared to other treatments, followed by juveniles fed on control (2.16±0.20%), D0 (1.86±0.11%), D50 (1.21±0.10%) and D75 (0.54±0.09%). *L. vannamei* had continuously grown during this study as shown in (Figure 1c). The daily weight gain (DWG) of *L. vannamei* during the feeding trial showed a significant difference among the treatments (ANOVA, $p<0.05$) (Figure 1c). Shrimp juveniles fed on Control (0.016±0.004 g day^{-1}), D0 (0.011±0.001 g day^{-1}) and D25 (0.016±0.002 g day^{-1}) showed similar values ($p>0.05$) of weight gain while DWG values for D50 and D75 were significantly different. Shrimps fed on D75 displayed the lowest DWG (0.002±0.004 g day^{-1}).



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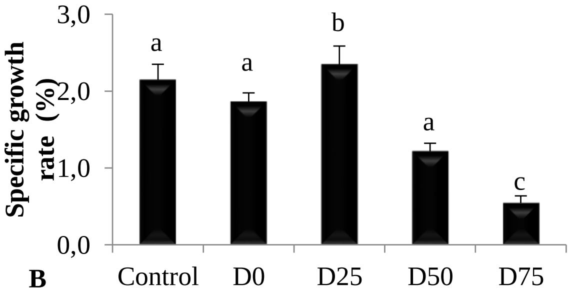

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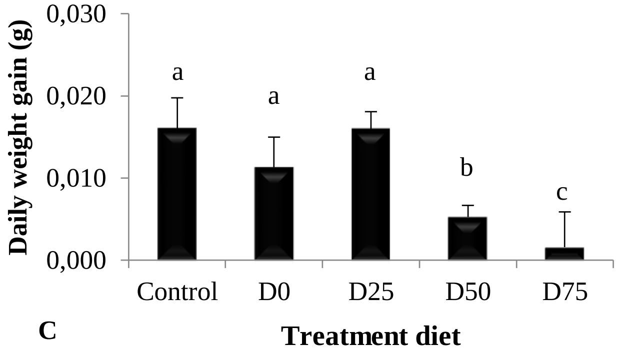

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Figure 1. (A) Final weight gain (FWG), (B) specific growth rate (SGR), and (C) daily weight gain (DWG) of *L. vannamei* juveniles after a 90-day feeding trial. *L. vannamei* juveniles were fed control and treatment diets containing D0 (0%), D25 (25%), D50 (50%) and D75 (75%) of fishmeal replacement with palm kernel meal. *a, b and c denote significant statistical differences at p<0.05

Palm kernel meal incorporation had been reported to be possible for diets in *M. rosenbergii* and *Oreochromis* sp. at levels between 20 and 30% inclusion. Kader *et al.* (2018) showed that growth parameters were significantly decreased in *M. rosenbergii* juveniles fed 40% PKM diet. However, supplementation of shrimp meal (2%) and squid meal (2%) in 40% PKM diet was significant in the recovery of depleted growth performance with the diet. Ng and Chong (2002) demonstrated that red tilapia (*Oreochromis* sp.) fed diets with 20% inclusion of PKM had similar growth performance with fish fed the control diet without PKM. Palm kernel by-product, however, could be incorporated only up to 2% in the diet of *P. monodon* (Rajaram *et al*., 2010). In the current study, inclusion levels of PKM at 25% demonstrated no adverse effect on weight gain, daily weight gain, and specific growth rate but deteriorated when FM was replaced with PKM at 50% and 75%. This result suggested that tolerance of the juvenile *L. vannamei* to fishmeal replacement with PKM is up to partial substitution at 25%.

This could be associated with the feeding habit of *L. vannamei*. This shrimp species is known as omnivore which habitually feeds on both animal and plant as diets. According to Rønnestad *et al*. (2013), omnivorous species are considered to have longer intestine than carnivorous and herbivorous species. These anatomy differences are related to the differences in the abundance of amylase digestive enzymes. High amount of digestive enzyme can be found in omnivores that influence the digestibility activity in the stomach and efficiently digest plant carbohydrate in their diets into energy (Hidalgo *et al*., 1999). This is because amylase enzyme is typically known as a dynamic carbohydrate digester enzyme and spare protein as muscle and lipid as fat (Warren *et al*., 2015). High survival percent after 90-day feeding trial among all treatments for Pacific white shrimp was observed between 98-100% (Figure 2). The highest survival of shrimps after fed on diets with different replacement levels was found in Control, D50 and D75 (100%) followed by those fed with D25 treatment diet (99%) and the lowest survival (98%) found in D0. However, there was no significant difference in survival among all treatment diets (ANOVA, p>0.05). Molina-Poveda *et al.* (2013) also found no differences and no relationship with treatment diets in survival of *L. vannamei* when fed with diets using corn gluten meal as protein sources.

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Similarly, López-Vela *et al.* (2014) observed there was no significant difference in survival (83-87%) of *L. vannamei* fed with a mixture of animal and plant protein. Survival of *L. vannamei* fed with the treatment diets in the current study is higher than those displayed by other studies; 71-89% with combination of soybean meal and distiller's dried grains with soluble (Cummins *et al*., 2013), 77-90% with corn gluten meal (Molina-Poveda *et al*., 2013) and 71-99% with soy protein concentrate and soybean meal (Xie *et al*., 2016). Even though the growth of shrimp deteriorated with treatments D50 and D75, however there was no relationship between mortality and treatment diets could be observed. Furthermore, the experimental conditions for this study were suitable for *L. vannamei* as confirmed by reported high survival percent (98-100%) (p>0.05).

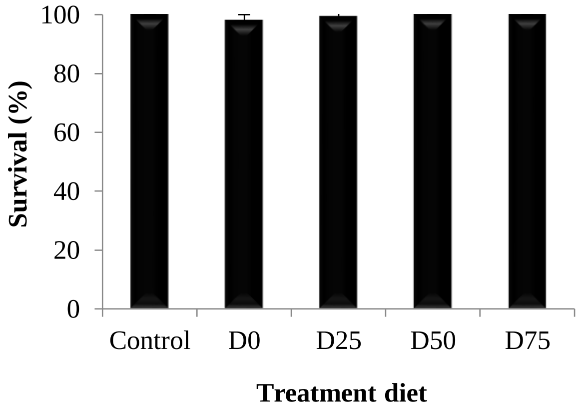

Figure. 2. Final survival (%) of *L. vannamei* juveniles after 90-day feeding trial. *L. vannamei* were fed Control, and treatment diets containing D0 (0%), D25 (25%), D50 (50%) and D75 (75%) of fishmeal replacement with palm kernel meal. There was no significant difference among the treatments (p>0.05).

Proximate composition of shrimps after feeding trial

The results of proximate composition in shrimp tissues after the feeding trial (Table 2). Protein levels increased in shrimp tissues for all treatment diets. Shrimps with the highest protein were those fed with D25 (67.6±0.87%) followed by D0 (67.1±0.10%), D50 (66.5±0.17%) and Control (65.6±0.30%). The least amount of protein was found in shrimps fed on D75 treatment diet (57.4±0.63%). Total protein concentration in shrimp tissues yielded a significant variation among all treatment diets (ANOVA, p<0.05). However, Lim *et al.* (1997) found that *L. vannamei* fed with formulated diets from canola meal showed no significant difference in their body protein content (p>0.05). Similarly, Bulbul and co-workers (2013) also found total protein composition in *M. japonicus* displayed no significant difference when fed with diets containing soybean meal (p>0.05). In the current study, the body protein content observed in shrimp tissues decreased when fed with high content of PKM. Ng et al. (2002) also observed the deterioration in the body protein content of red hybrid tilapia fed on fermented PKM based diets. On the other hand, Lim and Dominy (1990) found the increment of total protein in *L. vannamei* was corresponded with the increasing levels of soybean meal in the diets. Protein retention is considered as an important indicator for optimal supply and efficiency in nutrient utilisation (Deng *et al*., 2006). Reduction in nutrient utilisation of diets with PKM might be due to the presence of anti-nutritional factors (ANFs) such as phytic acid and tannins and oxalate (Akinyeye *et al*., 2011) which present bitter taste (Thakur *et al*., 2019; Vikram *et al*., 2020) and reduce the feed intake in shrimps. Therefore, it describes the lower growth performance of the shrimps in the present study when the shrimp juveniles were fed on D75.

The highest lipid content in body composition of shrimps was displayed by those fed on Control (4.33±2.96%) followed by D25 (4.32±0.67%), D0 (4.04±1.21%) and D50 (2.10±0.14%). Lipid content in shrimps fed on D75 showed the lowest concentration of 2.03±0.20%. There was no significant difference (ANOVA, $p>0.05$) in lipid content among all treatments. A similar trend has been observed by Harter et al. (2011), Chiu et al. (2016) and Sun et al. (2016) in which *L. vannamei* were fed with Barbados nut (*Jatropha curcas*) kernel meal, fermented cottonseed meal and fermented mixture of soybean meal and earthworm. The substitutions of fishmeal with the above-mentioned plant meals did not show significant variation in the total lipid content of shrimp body. Bulbul *et al.* (2013) also found that there was no significant effect in whole body lipid on *M. japonicus* fed diets with soybean meal ($p>0.05$). After the 90-day feeding trial, shrimps fed on D75 exhibited the highest accumulation of carbohydrate (16.75±0.04%) followed by D50 (16.65±0.04%), Control (16.04±0.03%) and D0 (14.72±0.01%) with slight variation. The lowest concentration of carbohydrate was observed in shrimps fed on D25 (14.67±0.07%). However, one way variance analysis showed no significant difference in carbohydrate content among treatments (ANOVA, $p>0.05$). Total carbohydrate contents were found generally low in all treatments. The current study showed similar results as in a sample of collected wild African river prawn, *Macrobrachium vollenhovenii* (16.1%) (Adeyeye & Adubiaro, 2004). A previous study by Ravichandran *et al.* (2009) found a lower amount of carbohydrate in the flesh of wild Indian white shrimp, *Penaeus indicus* (2.4%). Similarly, Gunalan *et al*. (2013) also found a lower carbohydrate in cultured *L. vannamei* (3.2%) compared to the current study. The present study also observed high content of total carbohydrate and low total protein fed on D50 and D75, and vice versa when fed on Control, D0 and D25 in the *L. vannamei* tissues. This finding was supported earlier by Gunalan *et al.* (2013) who also found that total carbohydrates tend to have inverse relationship with protein content in shrimp tissues. These results suggested that shrimps have limited ability in digesting carbohydrate in plant protein-based diets (Sun *et al*., 2016).

There was a significant difference in moisture concentration in shrimp tissue fed on all treatment diets (ANOVA, $p<0.05$). The highest total moisture was found in shrimps fed on D75 (13.66±0.31%) and the lowest was in D25 (6.07±0.09%). Meanwhile, D0, D50 and Control total moisture contents are 6.50±0.04%, 6.30±0.09% and 6.14±0.15%, respectively. A post hoc Tukey's test also showed the shrimps fed with D75 differed significantly in moisture content compared to other treatments ($p<0.05$). The present study displays a high body moisture content when fishmeal replacement levels with PKM increased. Iluyemi *et al.* (2010)

also observed the same trend in whole body moisture of red tilapia fed on diets with palm kernel cake (PKC). Body moisture of red tilapia increased when PKC level in diets increased. Similar pattern was observed in *L. vannamei* fed on diets when fishmeal was totally replaced with canola meal (Lim *et al*., 1997). They reported that the augmentation of body moisture of the shrimp was related to the increased levels of canola meal in the diets. Total ash content in shrimps is highly distributed in shrimps fed on D75 diet (10.12±0.12%) followed by D50 treatment (8.40±0.40%), Control (7.81±0.81%) and D0 (7.61±0.61%). Based on the one-way analysis of variance (ANOVA), ash distribution in shrimps showed significant difference in all treatment diets (p<0.05). Post hoc Tukey's tests interpreted that ash in shrimps fed Control, D0 and D25 were not significantly different at p>0.05. Ash in shrimps fed D50 and D75 showed a significant difference (Tukey's test, p<0.05). Total body ash content of *L. vannamei* in the current study was higher in shrimp fed D75 than in shrimp fed control and D0 diets. It is comparable with the study by Ng *et al.* (2002) who discovered that ash content of red hybrid tilapia was higher in PKM based diets compared to Control diets. In an earlier study, Iluyemi *et al*. (2010) also found the ash content of red tilapia increased when fed with PKC based diets. A previous study by Soltan *et al.* (2008) reported likewise, where whole body ash of nile tilapia escalated with the increment of cottonseed, sunflower, canola, sesame and linseed mixture in the diets. However, nearly none of the previous studies had reasoned out the positive correlation between plant protein-based diets with the body ash of cultured animals.

Table 2. Proximate composition of shrimp tissues (*L. vannamei*) before and after a 90-day feeding trial.

	Protein	Lipid	Carbohydrate	Ash	Moisture
Initial	10.74±0.70	3.24±0.12	73.04±0.06	9.08±0.14	3.90±0.07
Control	65.67±0.30[a]	4.33±2.96	16.04±0.03	7.81±0.81[a]	6.14±0.15[a]
D0	67.13±0.10[b]	4.04±1.21	14.72±0.005	7.61±0.61[a]	6.50±0.04[b]
D25	67.59±0.87[b]	4.32±0.67	14.67±0.07	7.34±0.34[a]	6.07±0.09[a]
D50	66.54±0.17[a,b]	2.10±0.14	16.65±0.04	8.40±0.40[b]	6.3±0.09[a,b]
D75	57.44±0.63[c]	2.03±0.20	16.75±0.04	10.12±0.12[c]	13.66±0.31[c]

*[a,b,c,d] denote significant statistical differences at p<0.05 in the same column.

Conclusions

The results obtained in this study have shown that 25% inclusion of palm kernel meal do not negatively affect the growth performance of *L. vannamei*. The addition of PKM above 50% significantly impaired the growth of the shrimp. However, the survival *of L. vannamei* seemed to not be affected by PKM inclusion in the diet. Higher PKM diets (D50 and D75) resulted in lower protein and lipid contents in shrimp. Prior treatments of PKM may be necessary to increase protein content and eliminate anti-nutritional compounds in the meal. PKM can be a suitable alternative ingredient for *L. vannamei* feeds, with great potential to partially replace fishmeal at 25% level without deteriorating the growth. The outcomes of this study are useful in providing better understanding on nutrients required by *L. vannamei* and proposing the use of PKM in their formulated feeds.

References

Adeyeye EI & Adubiaro HO. 2004. Chemical composition of shell and flesh of three prawn samples from Lagos lagoon. *Journal of the Science of Food and Agriculture*, 84(5):411-414.

Agunbiade J, Wiseman J & Cole DJA. 1999. Energy and nutrient use of palm kernels, palm kernel meal and palm kernel oil in diets for growing pigs. *Animal Feed Science and Technology*, 80(3-4):165-181.

Alimon AR. 2004. The nutritive value of palm kernel cake for animal feed. *Palm Oil Developments*, 40:12-14.

AOAC. 2005. Official Methods of Analysis of AOAC International, Eighteenth ed. AOAC International, Maryland.

Akinyeye RO, Adeyeye EI, Fasakin O & Agboola A. 2011. Physico-chemical properties and anti-nutritional factors of palm fruit products (*Elaeis guineensis* Jacq.) from Ekiti State Nigeria. *Electronic Journal of Environmental, Agricultural and Food Chemistry*, 10(5):2190-2198.

Awalludin MF, Sulaiman O, Hashim R, Nadhari WNAW. 2015. An overview of the oil palm industry in Malaysia and its waste utilization through thermochemical conversion, specifically via liquefaction. *Renewable and Sustainable Energy Reviews*, 50:1469-1484.

Biao X & Kaijin Y. 2007. Shrimp farming in China: Operating characteristics, environmental impact and perspectives. *Ocean & Coastal Management*, 50(7):538-550.

Bligh EG & Dyer WJ. (1959). A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology*, 37(8):911-917.

Briggs M, Funge-Smith S, Subasinghe RP, Phillips M. 2005. Introductions and movement of two penaeid shrimp species in Asia and the Pacific. Food and Agriculture Organization of the United Nations, Rome

Bulbul M, Koshio S, Ishikawa M, Yokoyama S & Abdul Kader M. 2013. Growth performance of juvenile kuruma shrimp, *Marsupenaeus japonicus* (Bate) fed diets replacing fishmeal with soybean meal. *Aquaculture Research*, 46(3):572-580.

Chiu ST, Wong SL, Shiu YL, Chiu CH, Guei WC & Liu CH. 2016. Using a fermented mixture of soybean meal and earthworm meal to replace fishmeal in the diet of white shrimp, *Penaeus vannamei* (Boone). *Aquaculture Research*, 47(11):3489–3500.

Cummins VC, Webster CD, Thompson KR & Velasquez A. 2013. Replacement of fishmeal with soybean meal, alone or in combination with distiller's dried grains with solubles in practical diets for pacific white shrimp, *Litopenaeus vannamei*, grown in a clear-water culture system. *Journal of the World Aquaculture Society*, 44(6): 775-785.

Cuzon G. 1989. Selected ingredients for shrimp feed. *Actes de Colloque*, 9:406-412.

Deng J, Mai K, Ai Q, Zhang W, Wang X, Xu W & Liufu Z. 2006. Effects of replacing fishmeal with soy protein concentrate on feed intake and growth of juvenile Japanese flounder, *Paralichthys olivaceus*. *Aquaculture*, 258(1-4):503-513.

El-Sayed AFM. 1999. Alternative dietary protein sources for farmed tilapia, *Oreochromis* spp. *Aquaculture*, 179(1-4):149-168.

Ezieshi EV & Olomu JM. 2008. Nutritional evaluation of palm kernel meal types: 2. Effects on live performance and nutrient retention in broiler chicken diets. *African Journal of Biotechnology*, 7(8).

FAO. 2003. Food energy-methods of analysis and conversion factors. Report of a Technical Workshop, Rome, 3-6 December 2002.

Gunalan B, Nina TS, Soundarapandian P & Anand T. 2013. Nutritive value of cultured white leg shrimp *Litopenaeus vannamei*. *International Journal of Fisheries and Aquaculture*, 5(7):166-171. https://doi: 10.5897/IJFA2013.0333

Harter T, Buhrke F, Kumar V, Focken U, Makkar HPS & Becker K. 2011. Substitution of fishmeal by *Jatropha curcas* kernel meal: effects on growth performance and body composition of white leg shrimp (*Litopenaeus vannamei*). *Aquaculture Nutrition*, 17(5):542-548.

Hasan BMA, Guha B & Datta S. 2012. Optimization of feeding efficiency for cost effective production of *Penaeus monodon* Fabricius in semi-intensive pond culture system. *Journal of Aquaculture Research & Development*, 3(149).

DOI: https://doi.org/10.31093/joas.v6i2.145

Hem S, Toure S, Sagbla C & Legendre M. 2008. Bioconversion of palm kernel meal for aquaculture: Experiences from the forest region (Republic of Guinea). *African Journal of Biotechnology*, 7(8):1192-1198.

Hidalgo M, Urea E & Sanz A. 1999. Comparative study of digestive enzymes in fish with different nutritional habits. Proteolytic and amylase activities. *Aquaculture*, 170(3-4):267-283.

Iluyemi FB, Hanafi MM, Radziah O & Kamarudin MS. 2010. Nutritional evaluation of fermented palm kernel cake using red tilapia. *African Journal of Biotechnology*, 9(4):502-507.

Kader MA, Bulbul M, Abol-Munafi AB, Sheriff SBM, Keong NW, Ali ME & Koshio S. 2018. Effect of replacing fishmeal with palm kernel meal supplemented with crude attractants on growth performance of *Macrobrachium rosenbergii*. *AACL Bioflux*, 11(1).

Kua BC, Fariduddin OM, Marzukhi O & Iftikhar AMA. 2018. Mortality outbreaks in whiteleg shrimp (*Penaeus vannamei* Boone 1931) cultured in Peninsular Malaysia. *Asian Fisheries Society*, 31S:242-256.

Liao IC & Chien YH. 2011. The Pacific white shrimp, *Litopenaeus vannamei*, in Asia: the world's most widely cultured alien crustacean. In: Galil BS, Clark PF, Carlton JT (eds.) In the Wrong Place-Alien Marine Crustaceans: Distribution, Biology and Impacts. Springer, Dordrecht, pp. 489-519.

Lim C & Dominy W. 1990. Evaluation of soybean meal as a replacement for marine animal protein in diets for shrimp (*Penaeus vannamei*). *Aquaculture*, 87(1):53-63.

Lim C, Beames RM, Eales JG, Prendergast AF, McLeese JM, Shearer KD & Higgs DA. 1997. Nutritive values of low and high fibre canola meals for shrimp (*Penaeus vannamei*). *Aquaculture Nutrition*, 3(4):269-279.

López-Vela M, Puente ME, Civera-Cerecedo R, Arredondo-Vega BO, Andreatta ER & Magallón-Barajas FJ. 2014. Characterization of wastewater generated by *Litopenaeus vannamei* after being fed experimental diets based on animal protein, vegetable protein and a commercial diet. *Aquaculture Research*, 45(12):1921-1931.

Molina-Poveda C, Lucas M & Jover M. 2013. Evaluation of the potential of Andean lupin meal (*Lupinus mutabilis* Sweet) as an alternative to fishmeal in juvenile *Litopenaeus vannamei* diets. *Aquaculture*, 410-411: 148-156.

Ng WK. 2003. The potential use of palm kernel meal in aquaculture feeds. *Aquaculture Asia*, 8(1):38-39.

Ng WK & Chong KK. 2002. The nutritive value of palm kernel meal and the effect of enzyme supplementation in practical diets for red hybrid tilapia (*Oreochromis* sp.). *Asian Fisheries Science*, 15:167-176.

Ng WK, Lim HA, Lim SL & Ibrahim CO. 2002. Nutritive value of palm kernel meal pretreated with enzyme or fermented with *Trichoderma koningii* (Oudemans) as a dietary ingredient for red hybrid tilapia (*Oreochromis* sp.). *Aquaculture Research*, 33(15):1199-1207.

Obirikorang KA, Amisah S, Fialor SC & Skov PV. 2015. Effects of dietary inclusions of oilseed meals on physical characteristics and feed intake of diets for the Nile Tilapia, *Oreochromis niloticus*. *Aquaculture Reports 1*:43-49.

Ochang SN, Fagbenro OA &Adebayo OT. 2007. Growth performance, body composition, haematology and product quality of the African Catfish (*Clarias gariepinus*) feed diets with palm oil. *Pakistan Journal of Nutrition*, 6(5):452-459.

Olsen RL & Hasan MR. 2012. A limited supply of fishmeal: impact on future increases in global aquaculture production. *Trends in Food Science & Technology*, 27:120-128.

Perez JF, Gernat AG & Murillo JG. 2000. The effect of different levels of palm kernel meal in layer diets. *Poultry Science*, 79:77-79.

Pratoomyot J, Bendiksen EÅ, Bell JG & Tocher DR. 2010. Effects of increasing replacement of dietary fishmeal with plant protein sources on growth performance and body lipid composition of Atlantic salmon (*Salmo salar* L.). *Aquaculture*, 305(1-4):124-132.

Rajaram V, Syama DJ, Ambasankar K & Ahamad AS. 2010. Effect of dietary incorporation of palm kernel cake on growth, digestibility and amino acid profiles of black tiger shrimp (*Penaeus monodon*). *Indian Journal of Animal Nutrition*, 27(4):432-440.

Ravichandran S, Rameshkumar G, Prince AR. 2009. Biochemical composition of shell and flesh of the Indian white shrimp *Penaeus indicus* (*H. milne* Edwards 1837). American-*Eurasian Journal of Scientific Research*, 4(3):191-194.

Resan AN & Obaydi TSMA. 2019. Effect of using raw palm kernel meal and treated with local enzymes (cellulose, amylase, and protease) instead of yellow corn in common carp fish (*Cyprinus carpio*) diets. *Plant Archives*, 19(2):1819-1823.

Richard L, Surget A, Rigolet V, Kaushik SJ & Geurden I. 2011. Availability of essential amino acids, nutrient utilisation and growth in juvenile black tiger shrimp, *Penaeus monodon*, following fishmeal replacement by plant protein. *Aquaculture*, 322-323:109-116.

Rønnestad I, Yúfera M, Ueberschär B, Ribeiro L, Sæle Ø & Boglione C. 2013. Feeding behaviour and digestive physiology in larval fish: current knowledge, and gaps and bottlenecks in research. *Reviews in Aquaculture*, 5(1):S59-S98.

Soltan MA, Hanafy MA & Wafa MIA. 2008. Effect of replacing fishmeal by a mixture of different plant protein sources in Nile tilapia (*Oreochromis niloticus* L.) diets. *Global Veterinaria*, 2(4):157-164.

Suárez JA, Gaxiola G, Mendoza R, Cadavid S, Garcia G, Alanis G & Cuzon G. 2009. Substitution of fishmeal with plant protein sources and energy budget for white shrimp *Litopenaeus vannamei* (Boone, 1931). *Aquaculture*, 289(1-2):118-123.

Sun H, Tang JW, Yao XH, Wu YF, Wang X & Liu Y. 2016. Effects of replacement of fishmeal with fermented cottonseed meal on growth performance, body composition and haemolymph indexes of Pacific white shrimp, *Litopenaeus vannamei* Boone, 1931. *Aquaculture Research*, 47(8):2623-2632.

Thakur A, Sharma V & Thakur A. 2019. An overview of anti-nutritional factors in food. *International Journal of Chemical Studies*, 7(1):2471-2479.

Vikram N, Katiyar SK, Singh CB, Husain R & Gangwar LK. 2020. A review of anti-nutritional factors. *International Journal of Current Microbiology and Applied Sciences*, 9(5): 1128-1137.

Warren FJ, Zhang B, Waltzer G, Gidley MJ & Dhital S. 2015. The interplay of α-amylase and amyloglucosidase activities on the digestion of starch in *in vitro* enzymic systems. *Carbohydrate Polymers*, 117:192-200.

Xie SW, Liu YJ, Zeng S, Niu J & Tian LX. 2016. Partial replacement of fish-meal by soy protein concentrate and soybean meal based protein blend for juvenile Pacific white shrimp, *Litopenaeus vannamei*. *Aquaculture*, 464: 296-302.

Zhang XD., Wu TX, Cai LS & Zhu Y.F. 2007. Influence of fasting on muscle composition and antioxidant defenses of market-size *Sparus macrocephalus*. *Journal of Zhejiang University Science B*, 8(12):906–911.