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The use of corn distiller's dried grains with solubles as a protein source in practical diets for Pacific white leg shrimp *Litopenaeus vannamei*

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ABSTRACT

A two-stage growth trial using identical diets was conducted to examine the viability of partially replacing soybean meal (SBM) with corn distiller's dried grain with solubles (DDGS) simulating the commercial growth cycle of shrimp from 1 g to 19 g body weight. In both trials, the reference diet was formulated using 25 % SBM, 8 % fish meal (FM) and 20 % poultry by-product meal (PBPM). Test diets were formulated by replacing SBM with 5 %, 10 % and 15 % of DDGS, respectively. All diets contain approximately 36 % crude protein and 7 % crude lipid. In trial 1, fifteen shrimp with average initial weight of 1.04 ± 0.04 g were stocked into 98 l aquaria tank (equivalent to 150 shrimp m^{-2}) in a completely randomized design with ten replicates per treatment and fed with the experimental diets for 52 days. In trial 2, shrimp (5.2 ± 0.2 g) were stocked randomly into 200 L clear tanks at a density of 50 shrimp per tank (equivalent to 250 shrimp m^{-2}) with eight replicates per treatment and fed for 84 days. The results showed growth performance of shrimp in both studies was not affected as the dietary SBM was partially replaced with DDGS. There were no significant differences observed in terms of crude protein, fat content, dry matter and ash content of the shrimp in both studies. The results from this study demonstrated that corn DDGS could be used up to 15 % in commercial feed formulations without causing any adverse effect on growth, feed conversion, nutrient utilization efficiency and whole body composition. Since the price per unit protein of corn DDGS is much cheaper than SBM, the use of corn DDGS could offer the development of sustainable and economically sound practical diets for Pacific white leg shrimp *L. vannamei*.

1. Introduction

Global production of shrimp *Litopenaeus vannamei* has experienced a dramatic increase from 2.688 million tons in 2010 to reach 4.966 million tons in 2018 (FAO, 2020). This expansion has resulted in an increasing demand for good quality shrimp feed and ingredients to support the productivity and efficiency within the production system. However, continued growth of shrimp production is basically unsustainable if fish meal (FM) remains the primary protein source used in shrimp diet composition (Hardy, 2010). This mainly due to the heightened concern about fisheries resources when 27 % of the global FM used in the aquafeed sector goes into feeds for marine shrimp (Tacon and Metian, 2008). The condition has worsened with the limited supply and increasing price of FM resulting in an increased cost of shrimp feed (Sookying and Davis, 2011). Therefore, alternatives for FM are needed to increase the cost-efficiency in shrimp production system.

Among alternative protein sources for vannamei, processed soybean possesses many qualities that can replace dietary FM because of its high protein content, high digestibility, relatively well-balanced amino acid profile, steady supply and reasonable price (Novriadi, 2017; Sookying et al., 2013; Davis and Arnold, 2000). In addition to soybean meal, more alternative protein sources should be investigated for use in shrimp feed. Sookying and Davis (2011) reported that diet containing high levels of SBM in combination with poultry by-product meal (PBM), distiller's dried grains with solubles (DDGS) or pea meal (PM) and in the absence of FM had no negative impact on growth performance of shrimp reared under field conditions. However, deficiency in essential amino acids (EAAs), such as methionine, lysine and tryptophan, as well as the

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presence of anti-nutritional factors (ANFs) might limit the wider use of SBM in shrimp feed (Sookying and Davis, 2011; Lim and Dominy, 1992). Consequently, there will likely be a need for other plant-protein sources in combination with SBM to provide a balanced diet for shrimp.

Corn distiller's dried grain with solubles (DDGS) as the co-product from the ethanol industry, containing moderate protein, lipid and phosphorus level, as well as vitamin and trace minerals, might be a good candidate to partially replace the use of SBM and enhance the efficacy of plant-protein sources for shrimp. DDGS is proven to be a good source of methionine (Diógenes et al., 2019), less expensive than SBM (Rhodes et al., 2015) and does not contain the anti-nutritional factors (ANFs) as contained in SBM (Wilson and Poe, 1985; Shiau et al., 1987). It has been reported that the use of lipid-extracted DDGS to substitute the use of SBM on an iso-nitrogenous basis supplemented with lysine (*Lys*) could be incorporated at levels up to 20 % in diets for Pacific white leg shrimp *Litopenaeus vannamei* without any adverse effect on shrimp growth (Rhodes et al., 2015). Moreover, Achupallas et al. (2016) reported that up to 150 g kg^{-1} of grain distillers dried yeast (GDDY) can be used in commercial shrimp feed formulation without affecting the growth performance of Pacific white leg shrimp. However, information on the use of corn DDGS in a commercial shrimp diet and their effects on the growth and composition of the shrimp throughout the culture life cycle is limited. Therefore, the present study was designed to evaluate the growth performance and nutrient utilization efficiency of Pacific white leg shrimp in response to several inclusion levels of corn DDGS in a commercial diet formulation.

2. Materials and methods

2.1. Experimental diets

Experimental diets were formulated to contain approximately 36 % crude protein and 7 % crude lipid with feed formulation presented in Table 2. For both growth trials, the reference diet was designed with fish meal (FM), poultry by-product meal (PBPM) and soybean meal (SBM) as the primary ingredients. Three experimental diets containing 5 %, 10 % and 15 % of DDGS (*as is*) served as replacement of SBM and labeled as D5, D10, and D15, respectively. All diets were produced at PT. Suri Tani Pemuka (Banyuwangi Feedmill, East Java, Indonesia) using commercial steam-pelleting process with diameter of 1 mm. Dry pellets were packed in sealed bags, and stored in a freezer until further use. Chemical and essential amino acids (EAAs) compositions of experimental diets were analyzed at Evonik (SEA) Pte. Ltd (Singapore) and presented in Table 3. Nutritional profile of SBM and DDGS are given in Table 1, while the proximate and amino acid analysis are given in Table 3.

2.2. Growth trials

To simulate the commercial grow-out cycle, the trial covered the growth of the shrimp from 1 g to a marketable size of 19–20 g. In tank conditions, this would run the risk of poor survival rates which would render the results invalid. In order to achieve the requisite survival rates and growth increment for this study, the growth trials were divided into two and carried out in two different locations. In trial 1, the growth trial was performed at PT. Batam Dae Hae Seng research station (Batam, Indonesia). Pacific white leg shrimp post larvae (PL) were obtained from PT. Maju Tambak Sumur (Kalianda, Lampung, Indonesia) and nursed in a semi-indoor recirculating system. PL were fed with a commercial feed (Evergreen Feed 922 series CP 35 % and CF 5 %, Lampung, Indonesia) for three weeks to a suitable size. At the start of the trial, fifteen shrimp with average initial weight of 1.04 ± 0.04 g were stocked into 70 × 35 × 40 cm (98 L) aquaria tank (equal with 150 shrimp m^{-2}). Each treatment consisted of ten replicates in a completely randomized design. Shrimp from all trials were maintained under a natural photoperiod for 52 days. During the trial, shrimp were fed four times per day at 07:00, 11:00, 15:00 and 19:00 and feeding was pre-programmed assuming the normal growth of shrimp and feed conversion ratio of 1.5. Daily allowances of feed were adjusted based on observed feed consumption and weekly counts of the shrimp. Trial 2 was performed at Japfa Aquaculture Research Station (PT. Suri Tani Pemuka, Banyuwangi, East Java, Indonesia). Pacific white shrimp post larvae (PL) were obtained from Suri Tani Pemuka hatchery (STP, Banyuwangi, East Java, Indonesia) and fed with commercial STP shrimp feed during the acclimatization period. Shrimp with an average weight of 5.2 ± 0.2 g were randomly distributed into four experimental groups comprising eight replicates in 200 L clear tanks at a density of 50 shrimp per tank (or 250 shrimp m^{-2}) for 12 weeks. During the trial, shrimp in each dietary treatment were hand-fed to apparent satiation eight times per day at 08:00, 09:30, 11:00, 12:30, 14:00, 15:30, 17:00 and 18:30. Dead shrimp were carefully removed and recorded during experimental period. Water quality was maintained by a recirculating system with physical and biological filters. Parameters including pH, dissolved oxygen (DO), water temperature and salinity were measured four times daily using Aqua TROLL 500 Multiparameter Sonde instrument and connected to AquaEasy apps (Bosch, Singapore) for real-time data monitoring and recording system.

Table 1
Nutrient composition of soybean meal (SBM) and corn distillers dried grains with soluble (DDGS).

Nutrient composition (as is basis)	SBM	DDGS
Chemical analysis[a]		
Dry matter (%)	90.33	87.97
Crude protein (%)	46.21	27.70
Crude lipid (%)	0.82	6.38
Ash (%)	6.22	4.73
Phosphorus (%)	0.94	0.85
Gross energy (MJ/kg)*	17.15	17.23
Amino acids analysis[b]		
Methionine (%)	0.59	0.54
Lysine (%)	2.91	0.92
Threonine (%)	1.79	1.07
Tryptophan (%)	0.62	0.23
Arginine (%)	3.49	1.35
Isoleucine (%)	2.14	1.02
Leucine (%)	3.51	3.13
Valine (%)	2.21	1.36
Histidine (%)	1.22	0.77
Phenylalanine (%)	2.39	1.37

* Gross energy is calculated from crude protein (23.6 kJ/g), crude lipid (38.5 kJ/g) and nitrogen free extract (17.3 kJ/g).
[a] Chemical composition was analyzed by PT Suri Tani Pemuka, Indonesia.
[b] Amino acids composition was analyzed by Evonik (SEA) Pte Ltd, Singapore.

2.3. Growth sampling

At the end of growth trials, the shrimps were starved for 24 h before weighing and counting. The final body weight (FBW), feed intake (FI), feed conversion ratio (FCR), thermal growth coefficient (TGC) and feed cost per weight gain (FCG) as follows:

$$FCR = \frac{feed \quad given \quad (g)}{alive \quad weight \quad gain \quad (g)}$$

$$FCG = \frac{feed \quad cost}{weight \quad gain \quad (g)}$$

$$\%SR = \frac{final \quad number \quad of \quad shrimp}{initial \quad number \quad of \quad shrimp} \times 100$$

$$TGC = \frac{FBW^{1/3} - IBW^{1/3}}{\sum_d T} \times 100$$

Table 2
Ingredient composition and formulation cost of experimental diets containing four graded levels of corn distillers dried grains with solubles (DDGS) for trial 1 and 2.

Ingredient (%)	Diet			
	D0	D5	D10	D15
Soybean meal[a]	25.0	22.5	20.0	17.5
Poultry by-product meal[b]	20.3	20.3	20.3	20.3
Fishmeal[c]	8.0	8.0	8.0	8.0
Corn DDGS[d]	0.0	5.0	10.0	15.0
Tuna hydrolysate[e]	2.0	2.0	2.0	2.0
Squid liver powder[f]	6.0	6.0	6.0	6.0
Wheat flour[g]	31.9	29.3	26.8	24.2
Soy lecithin[h]	1.5	1.5	1.5	1.5
Fish oil[i]	1.0	1.0	1.0	1.0
Monocalcium phosphate[j]	1.8	1.8	1.8	1.8
L-lysine[k]	0.00	0.04	0.09	0.14
DL-methionine[l]	0.19	0.18	0.17	0.17
L-threonine[k]	0.08	0.08	0.08	0.09
Mineral premix[m]	1.20	1.20	1.20	1.20
Vitamin premix[m]	0.41	0.41	0.41	0.41
Magnesium sulphate[n]	0.35	0.35	0.35	0.35
Choline chloride[k]	0.20	0.20	0.20	0.20
Antimold[o]	0.12	0.12	0.12	0.12
Formulation cost (IDR/kg)*	10.142	10.037	9.933	9.833

* CP = Crude protein.
[*] Formulation cost was based on the price of all ingredients on April 1st, 2021. The exchange rate IDR to USD was 14.577. (IDR = Indonesian Rupiah).
[a] Dehulled Solvent Extracted Soybean Meal, Argentina (CP: 64–65 %).
[b] Griffin Industries, USA (CP: 67–70 %).
[c] Foodcorp, S.A., Chile (CP: 46–48 %).
[d] US Grains Council, USA (CP: 28–29 %).
[e] SPF Diana, Thailand.
[f] Hana Industrial Co. Ltd, South Korea.
[g] PT Agristar Grain, Indonesia.
[h] Shandong Maowei International Trade Co. Ltd., China.
[i] Pesquera La Portada S.A., Chile.
[j] Sinochem YunLong, Co. Ltd, China.
[k] PT Dian Cipta Perkasa, Indonesia.
[l] Evonik Nutrition & Care GmbH, Hanau, Germany.
[m] PT DSM Nutritional Products, Indonesia.
[n] PT Jannisika Sumber Jaya, Indonesia.
[o] PT Tienyen International, Indonesia.

where FBW is final body weight, IBW is initial body weight, T is water temperature (°C) and dT is number of trial days.

2.4. Whole body composition and nutrient utilization efficiency

Upon termination of the trial, three shrimp from each tank or thirty shrimp per treatment in trial 1 and all individual shrimp from each tank in trial 2 were randomly sampled and stored at − 60 °C for whole body composition analysis. Prior to the chemical and EAAs analysis, dried whole shrimp were blended and chopped in a mixer according to the standard methods established by Association of Official Analytical Chemists. The whole body composition of shrimp in trial 1 was analyzed by Fish Nutrition laboratory, Bogor Agricultural University (Bogor, West Java, Indonesia). Meanwhile, in trial 2, chemical and EAAs composition of the whole body of shrimp were performed at the Evonik (SEA) Pte. Ltd (Singapore) using Biochrom 30 + Series of Amino Acid analyzers. In trial 2, the whole-body composition analysis was used to calculate nutrient utilization efficiency (NUE) with the following equation: NUE = [[(FBW × nutrient final) − (IBW × nutrient initial)]/nutrient intake] × 100, where nutrient = dry matter, protein, fat, ash, phosphorus and EAAs.

2.5. Statistical analysis

All data were analyzed using one-way analysis of variance (ANOVA) to determine the significant difference ($P < 0.05$) among the treatment means followed by the Tukey's multiple comparison test to determine difference between treatments means in each trial. The pooled standard errors were used across all the growth parameters as the variance of each treatment was the same. Statistical analyses were conducted using SAS system (V9.4, SAS Institute, Cary, NC, USA).

Table 3
Chemical and essential amino acids composition of experimental diets used for trial 1 and 2.

Nutrient composition (as is basis)	Diet			
	D0	D5	D10	D15
Chemical analysis[a]				
Dry matter (%)	91.58	90.37	89.91	90.88
Crude protein (%)	36.90	35.60	35.56	37.49
Crude lipid (%)	7.23	7.13	7.76	7.84
Ash (%)	9.11	9.37	8.82	9.21
Phosphorus (%)	1.55	2.03	1.54	1.84
Gross energy (MJ/kg)*	17.70	17.78	17.87	17.95
Amino acid analysis[b]				
Methionine (%)	0.84	0.85	0.86	0.89
Lysine (%)	2.07	2.03	2.00	2.09
Threonine (%)	1.46	1.46	1.42	1.49
Tryptophan (%)	0.41	0.40	0.38	0.39
Arginine (%)	2.36	2.36	2.25	2.37
Isoleucine (%)	1.50	1.51	1.43	1.54
Leucine (%)	2.59	2.63	2.56	2.75
Valine (%)	1.71	1.73	1.66	1.78
Histidine (%)	0.97	0.97	0.95	0.85
Phenylalanine (%)	1.62	1.64	1.55	1.63

[*] Gross energy is calculated from crude protein (23.6 kJ/g), crude lipid (38.5 kJ/g) and nitrogen free extract (17.3 kJ/g).
[a] Chemical composition was analyzed by PT Suri Tani Pemuka, Indonesia.
[b] Amino acids composition was analyzed by Evonik (SEA) Pte Ltd, Singapore.

3. Results

3.1. Growth performance

From the growth performance results on trial 1, the FBW, FI, TGC and FCR of Pacific white leg shrimp *L. vannamei* fed with diets containing 5 %, 10 % and 15 % of DDGS to replace SBM were not significantly affected ($P < 0.05$). However, numerically, the inclusion of 5 % DDGS into the basal diet provided better FBW, FCR and TGC compared to other treatments (Table 4). In trial 2 The FBW, WG, TGC, FCR and SR did not differ significantly across dietary treatments. For both trials, numerically, the feed cost per weight gain (FCG) was lower in shrimp fed with corn DDGS compared to SBM. The overall mean and standard deviation of water quality observed in both trials were within the acceptable range for the culture of *L. vannamei*. On trial 1, temperature, DO, pH and salinity were maintained at 28.60 ± 1.21 °C, 5.84 ± 0.35 mg L^{-1}, 7.75 ± 0.20 and 23.90 ± 6.28 ‰, respectively and on trial 2, temperature, DO, pH and salinity were maintained at 30.8 ± 0.9 °C, 4.95 ± 0.53 mg L^{-1}, 7.70 ± 0.25 and 19.5 ± 0.6 ‰, respectively.

3.2. Whole body composition and nutrient utilization efficiency

Table 5 shows there is no significant difference in terms of proximate composition of the whole body of the shrimp at the end of growth trial in both trials 1 and 2. This also showed the inclusion of corn DDGS to partially replace SBM did not significantly affect the proximate and amino acid composition in the whole body of shrimp across all treatments. With regard to nutrient utilization efficiency (NUE) on trial 2

Table 4
Growth, feed intake, feed conversion and feed cost per gain of Pacific white leg shrimp from two separate feeding trials. The mean value consists of ten and eight replicates from trial 1 and 2, respectively.

Diet	IBW[a] (g)	FBW[b] (g)	TGC[c]	FI[e] (g/shrimp)	FCR[d]	FCG[f] (IDR/kg gain)	Survival (%)
Trial 1 period is 52 days							
D0	1.04	10.17	0.077	16.83	1.85	18.783	86.79
D5	1.06	10.90	0.080	16.85	1.72	17.289	89.42
D10	1.03	10.30	0.078	16.81	1.82	18.077	90.17
D15	1.03	10.17	0.078	17.17	1.89	18.541	90.75
PSE[g]	0.0126	0.2367	0.0011	0.2220	0.0447	445.5	2.3956
p-value	0.2573	0.0856	0.2257	0.5969	0.0525	0.0822	0,5985
Trial 2 period is 84 days							
D0	5.20	18.51	0.035	27.56	2.08	21.056	67.50
D5	5.19	19.29	0.036	28.20	2.00	20.063	70.00
D10	5.17	18.90	0.036	28.91	2.11	21.003	70.75
D15	5.19	19.49	0.037	29.90	2.10	20.684	66.00
PSE	0.0749	0.3741	0.0007	0.8491	0.0707	703.2	6.6299
p-value	0.9919	0.2342	0.3009	0.2251	0.6192	0.7079	0.7253

[a] IBW = initial body weight.
[b] FBW = final body weight.
[c] TGC = thermal-unit growth coefficient.
[d] FCR = feed conversion ratio.
[e] FI = feed intake.
[f] FCG = feed cost per weight gain.

Table 5
Whole body composition of Pacific white leg shrimp fed the experimental diets on trial 1 for 52 days and trial 2 for 84 days.

Composition (%)	Diet				PSE	*p-value*
	D0	D5	D10	D15		
Trial 1						
Dry Matter	27.33	26.88	27.11	26.61	0.2749	0.6151
Protein	20.12	20.35	20.01	19.89	0.2453	0.3483
Fat	2.02	1.64	2.04	2.06	0.1830	0.3758
Ash	3.01	3.14	3.28	3.14	0.1493	0.6811
Trial 2						
Dry Matter	22.59	22.53	21.24	21.91	0.7373	0.5904
Protein	16.04	16.08	15.08	15.66	0.5560	0.6107
Fat	0.81	0.78	0.79	0.74	0.0536	0.8673
Ash	2.31	2.39	2.21	2.31	0.0783	0.5190
Phosphorus	0.30	0.32	0.29	0.31	0.0147	0.5170
Methionine	0.34	0.34	0.32	0.33	0.0121	0.5484
Lysine	1.04	1.01	0.94	0.92	0.0418	0.2011
Threonine	0.53	0.54	0.50	0.52	0.0224	0.6315
Tryptophan	0.17	0.16	0.15	0.16	0.0056	0.3948
Arginine	1.11	1.11	1.02	1.16	0.0880	0.7663
Iso Leucine	0.60	0.61	0.57	0.58	0.0215	0.4920
Leucine	1.02	1.02	0.95	0.97	0.0362	0.5144
Valine	0.67	0.68	0.62	0.65	0.0250	0.5229
Histidine	0.32	0.32	0.29	0.31	0.0124	0.3578
Phenylalanine	0.62	0.61	0.57	0.59	0.0218	0.4890

(Table 6), the protein, fat, phosphorus, ash content and essential amino acid profile were not significantly affected when corn DDGS was used up to 15 % in the diet formulation.

4. Discussion

In recent years, increasing demand for ethanol as a fuel additive to decrease the dependency on fossil fuels has led to dramatic increase in the production of DDGS (Liu and Han, 2011; Outlook, 2007). Novel processing technologies to increase the nutritional value of DDGS has encouraged the use of DDGS in many aquaculture diets, primarily to decrease the cost of diet and balance the nutritional profile of the resulting feed (Rhodes et al., 2015). Results in this study show the use of corn DDGS up to 15 % to replace SBM had no negative effect to the growth of shrimp. Despite using different stocking densities and shrimp size, the FBW, SR, EG, TGC and FCR of Pacific white leg shrimp (*Litopenaeus vannamei*) in both trials were not significantly affected ($P < 0.05$). A similar response was reported by Sookying and Davis (2011) who found that diet containing 10 % DDGS had no negative impact on the growth performance of shrimp reared in 0.1 ha outdoor ponds. Thus, a diet with proper inclusion levels of DDGS can achieve similar growth performance as those from the more costly soy-protein and fish meal diets.

Table 6
Nutrient utilization efficiency (NUE) of Pacific white leg shrimp on trial 2 fed the experimental diets for 84 days. Values represent the mean of eight replicates.

NUE (%)	Diet				PSE	*p-value*
	D0	D5	D10	D15		
Dry Matter	12.62	13.32	11.85	12.24	1.5575	0.5941
Protein	22.03	22.87	20.55	21.22	1.1911	0.5898
Fat	6.08	6.18	5.51	5.02	0.5754	0.5173
Phosphorus	9.85	8.65	9.57	8.84	0.6137	0.5220
Ash	11.55	12.43	11.20	11.61	0.6721	0.6624
Methionine	21.25	21.86	18.99	18.91	1.1191	0.1999
Lysine	26.16	26.85	23.37	21.91	1.4473	0.1004
Threonine	19.00	20.08	17.75	17.93	1.2241	0.5662
Tryptophan	21.46	22.50	20.85	20.97	1.1518	0.7705
Arginine	23.98	25.21	22.29	25.54	2.7585	0.8588
Isoleucine	21.09	22.23	20.34	19.56	1.1340	0.4577
Leucine	20.64	21.17	19.07	18.27	1.1018	0.2847
Valine	20.55	21.58	19.34	18.87	1.1446	0.4032
Histidine	17.32	18.53	15.76	18.76	1.0676	0.2443
Phenylalanine	19.68	20.24	18.62	18.52	1.0734	0.6599

The major finding of this experiment was that the use of corn DDGS up to 15 % to partially replace the inclusion level of SBM resulted in similar response to the basal diet throughout the whole commercial grow-out cycle of the shrimp from 1 g to 19–20 g body weight. To simulate this in a single tank trial would have risked very poor survival rates thus invalidating the results. Conducting the trials in two phases allowed for the respectable survival rates of 86.79–90.75 % in trial 1 and 66.00–70.75 % in trial 2. The lower SR in trial 2 could have been attributed to the high stocking density. Weight gains of 881–933 % were seen in trial 1 and 266–286 % in trial 2.

In this study, the use of corn DDGS supplemented with proper level of lysine, methionine, and threonine could balance the nutritional profile of the diet and enhance the growth performance of shrimp. Since the price per unit protein of DDGS was cheaper than SBM, the use of DDGS to partially replace SBM in the present study could offer the development of sustainable and economically sound practical diet for Pacific white leg shrimp. Based on the total production cost for 1 kg of feed (Table 2), the inclusion of 5 %, 10 % and 15 % DDGS to partially replace SBM in this study could reduce the feed cost by 1.04 %, 2.06 %, and 3.05 %, respectively compared to the basal diet. Consequently, the FCG of the shrimp were also improved when compared with control diet.

Throughout the duration of the study, water quality parameters and levels of total ammonia observed in trial 1 and 2 were within the acceptable range for the shrimp.

In this study, no significant differences were observed in the crude protein, water content, fat content, dry matter and ash content in the whole-body of the shrimp. In addition, there were no significant differences on the EAAS composition. The nutrient utilization analysis also showed a comparative ability of shrimp to take up the nutrients efficiently from feed. Future work is needed to replicate this study in pond conditions to provide clear answer on the efficacy of corn DDGS to partially replace SBM on the growth and quality of shrimp. Future work is also required to determine the maximum inclusion rate of corn DDGS before we see shrimp growth is negatively affected.

5. Conclusion

With a two-stage trial, this study was able to conduct tank trials simulating the commercial grow-out cycle of shrimp up to 19 g size. Under the conditions of the present study, DDGS is a potential ingredient for shrimp feed and can be used up to 15 % to partially replace the use of SBM without compromising the growth and quality of Pacific white leg shrimp *L. vannamei*. As the price per unit protein of DDGS is cheaper than SBM, the use of DDGS could offer the development of sustainable and economically sound practical diets for shrimp.

CRediT authorship contribution statement

Romi Novriadi: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Draft creation, Supervision, Writing – original draft. **Erwin Suwendi:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Draft creation, Visualization. **Ronnie Tan:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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