Apparent digestibility of protein, energy, and amino acids in some selected feed ingredients for white shrimp Litopenaeus vannamei, Boone

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Keywords: White shrimp; Animal and plant ingredient; Digestibility; Amino acid availability

Abstract

The apparent digestibility coefficients of dry matter, crude protein, gross energy, and amino acids in steam dried fish meal (SDFM), local fish meal (LFM), Peruvian FAQ fishmeal (PFFM), shrimp head meal (SHM), soybean meal (SBM), dehulled soybean meal (DSBM), peanut meal (PM), cottonseed meal (CSM), canola meal (CM) and wheat flour (WF) were determined for white shrimp (0.28 ± 0.0 g, mean ± SE). The juvenile white shrimp were stocked in 300-l fiberglass tanks at a density of 30 shrimp per tank. The shrimp were fed to apparent satiation three times a day and the feeding experiment lasted for 8 weeks. Apparent digestibility coefficients for dry matter of test ingredients ranged from 28.5% to 75.1% and appeared to be related to the fiber, ash and starch content of the ingredients. Apparent digestibility coefficients (ADCs) of crude protein exceeding 90% were observed for SDFM. The soybean meal, peanut meal and dehulled soybean meal were more efficiently utilized than the other plant ingredients tested in this study with the average protein digestibility of 81.3%, 82.2% and 78.6% respectively. These values were close to, or equal to, those of Peruvian FAQ fishmeal, local fish meal and shrimp head meal, which showed values of 78.2%, 83.6%
and 81.0% respectively. The trend of ADCs for energy was similar to that of protein. Highest and lowest energy digestibility coefficients were found in SDFM and CM, respectively. Finally, amino acid availabilities cannot be estimated from the apparent digestibility coefficients of crude protein, the use of individual amino acid availability allows for more accuracy and specificity when determining the protein quality of an ingredient. These results provide more precise information concerning nutrition and energy utilization of feedstuffs for white shrimp and will allow ingredient substitutions in practical feed based on levels of available nutrients.

Introduction

White shrimp (Litopenaeus vannamei) is one of the most widely cultured shrimp in the world. In the recent years, aquaculture production of this species has rapidly increased in China because it has several desirable characteristics for high-density culture, such as rapid growth, good survival and disease tolerance. In intensive shrimp culture, feed accounts for 40–60% of the production costs, with fish meal accounting for a significant proportion of this cost.

Fish meal is the most important and a high demand protein source for many formulated diets due to its high level of protein, excellent amino acid profile which provides adequate levels of all essential amino acids, low carbohydrate level, high digestibility, and few anti-nutritional factors (Zhou et al., 2004). However, fish meal is one of the most expensive ingredients, and its prices will be higher in future owing to higher freight costs and the decision of the Peruvian government to slow down fish catch, in order to replenish anchovy supplies (Goettl, 2003). In China, in order to maximize growth of L. vannamei, commercial diets of L. vannamei still rely on fish meal as a key protein source despite of its price and availability. However, being too reliant on any one ingredient presents considerable risks associated with supply, price and quality fluctuations. As a strategy to reduce risk, the identification, development and use of alternatives to fishmeal in L. vannamei aquaculture diets remains a high priority. However, insufficient information is available concerning the availability of nutrients in feed ingredients for L. vannamei.

The determination of nutrient digestibility is the first step in evaluating the potential of an ingredient for use in the diet of an aquaculture species (Allan et al., 2000). Apparent digestibility coefficient assessment for feedstuffs is an essential prerequisite in screening the potential nutritive value of feed ingredients and in the development of nutritionally adequate diets at least cost (Irvin and Tabrett, 2005). Thus, the information on digestibility coefficients of feed ingredients is very useful not only to enable formulation of diets that maximize the growth of the animal by providing appropriate amounts of available nutrients, but also to limit the wastes produced by the animal. Presently, the ADCs of common feed ingredients have been reported for a few species of marine shrimp (Brunson et al., 1997; Lin et al., 2004). The objective of this work extended these determinations for the apparent digestibility coefficients for dry matter, crude protein, energy, and the availability of amino acids in selected feed ingredients and provide more information required for the formulation of diets for juvenile white shrimp.
Apparent digestibility of protein, energy, and amino acids in feed ingredients for *Litopenaeus vannamei*

**Materials and methods**

*Diet preparation*

The reference diet (RF) (Table 1) was formulated to satisfy the protein and lipid requirements of white shrimp (*Litopenaeus vannamei*). Eleven experimental diets composed of 70% reference diet and 30% of each of the test ingredients (on an air–dry weight basis) were prepared. These ingredients consisted of steam dried fish meal (SDFM), local fish meal (LFM), Peruvian FAQ fishmeal (PFFM), shrimp head meal (SHM), soybean meal (SBM), dehulled soybean meal (DSBM), peanut meal (PM), cottonseed meal (CSM), canola meal (CM), and wheat flour (WF). Yttrium oxide was used as an inert marker and was incorporated into the reference and experimental diets. Lipid and water were added to the premixed dry ingredients and thoroughly homogenised in a Hobart-type mixer. The 1.5-mm diameter pellets were wet-extruded, air-dried to about 10% moisture, sealed in plastic bags, and stored frozen (-20°C) until fed.

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<thead>
<tr>
<th>Ingredients</th>
<th>Amount (g kg⁻¹)</th>
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<tr>
<td>Steam dried fish meal a</td>
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</tr>
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<tr>
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<tr>
<td>Monocalcium phosphate b</td>
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<tr>
<td>Vitamin mixture d</td>
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</tr>
<tr>
<td>Mineral mixture d</td>
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<tr>
<td>Ascorbic acid Polyphosphate d</td>
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<tr>
<td>Yttrium oxide Y₂O₃ e</td>
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</tr>
<tr>
<td>Test ingredient</td>
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</table>

<table>
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<td>Beer yeast b</td>
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<td>Soy lecithin b</td>
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<td>Mineral mixture d</td>
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<tr>
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<tr>
<td>Yttrium oxide Y₂O₃ e</td>
<td>0.07</td>
</tr>
<tr>
<td>Test ingredient</td>
<td>300</td>
</tr>
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</table>

**Experimental procedures**

Juvenile white shrimps obtained from a commercial hatchery of Evergreen Group Hatchery (Guangdong, China), and kept in 300-L circular fiberglass tanks for two weeks acclimatization. During the acclimatization period, the shrimp were fed the reference diet. At the beginning of the experiment, healthy shrimp with an initial body weight of 0.28 ± 0.01 g were distributed randomly into 36 fiberglass tanks (300 l, 3 tanks / diet,
30 shrimp / tank). Filtered seawater (salinity, 29-30 g l\(^{-1}\)) was supplied to each tank at a flow rate of 1.0 L min\(^{-1}\) in a flow through system. During the experimental period, the water temperature, dissolved oxygen and ammonia were 28.0 ± 2 °C, 6.97 ± 0.03 mg l\(^{-1}\) and 0.08 ± 0.01 mg l\(^{-1}\), respectively. Natural light cycle was used in the feeding trial.

**Fecal collection techniques**

Diets were randomly assigned to aquaria and shrimp fed four weeks prior to the beginning of fecal collection. Triplicate groups of shrimp were fed the reference and experimental diets three times daily at 8:00, 12:00 and 18:00 with 8-10% body weight per day. Feces, molts and dead shrimp were removed by siphoning from tanks before the first feeding of the day. Fecal samples were collected twice a day from each tank (09:30 and 13:30 hours) and were siphoned from each tank into separate 1-L bottles. Each collection bottle was rinsed into a dish and only intact faecal strands were removed with forceps for drying. Feces collected were immediately transferred on filter paper 60 min at 4°C and stored at -20°C. Daily fecal samples from each tank were pooled over the course of the experiment until sufficient sample was available for chemical analyses.

**Chemical analyses**

Crude protein, crude lipid, moisture, gross energy, crude fiber and phosphorus content in diets, test ingredients and feces were determined following standard methods (AOAC, 1995). Crude protein (N 6.25) was determined by the Kjeldahl method after acid digestion using an Auto Kjeldahl System (1030-Auto-analyzer, Tecator, Sweden). Crude lipid was determined by the ether extraction method using a Soxtec System HT (Soxtec System HT6, Tecator, Sweden). Moisture was determined by oven-drying at 105°C for 24 h. Gross energy was determined using an adiabatic bomb calorimeter. Amino acid composition in diets, test ingredients and feces were analyzed by a commercial laboratory using a column (Hitachi, Model 835-50, Hitachi, Tokyo, Japan) equipped with a column (Hitachi custom ion exchange resin no. 2619). Yttrium oxide content of diets and feces were determined by ICP atomic emission spectrophotometry [IRIS Advantage (HR), Thermo Jarrell Ash, Woburn, USA] at the Centralized Analytical Laboratory at Sun Yat-sen University, China.

**Digestibility determinations and Statistical analysis**

Apparent digestibility coefficients (ADCs) for dry matter, crude protein, energy and availability of amino acids in the diets were determined with the following equations (Cho and Kaushik, 1990):

\[
ADC \text{ of nutrients or energy } \% = 100 \times [1 - (Y_2O_3 \text{ in diet} / Y_2O_3 \text{ in feces}) \times (% \text{ nutrient in feces/ % nutrient in diet})]
\]

The ADCs of the test ingredients (ADCI) were calculated based on the digestibility of the reference diet and test diets using the equation of Forster (1999):

\[
\text{Nutr.AD}_{\text{ingredient}} =\left[\left(70\% \times \text{Nutr}_{\text{basal}} + \text{Nutr}_{\text{ingredient}} \times 30\%\right) \times \text{AD}_{\text{test}} - \left(70\% \times \text{Nutr}_{\text{basal}} \times \text{AD}_{\text{basal}}\right)\right] / (\text{Nutr}_{\text{ingredient}} \times 30\%)
\]

Where Nutr.AD\text{ingredient} is the digestibility of a given nutrient from the ingredient included in the test diet at 30%. AD\text{test} is the apparent digestibility of the test diet. AD\text{basal} is the apparent digestibility of the basal diet, which makes up 70% of the test diet.
Apparent digestibility of protein, energy, and amino acids in feed ingredients for *Litopenaeus vannamei*

Nutrient, Nutr<sub>test</sub> and Nutr<sub>basal</sub> are the levels of the nutrient of interest in the ingredient, test diet and basal diet, respectively.

Results are expressed as mean ±SE. All data were subjected to one-way analysis of variance. When significant differences occurred, the group means were further compared with Duncan’s multiple-range tests. All statistical analyses were performed using the SPSS 11.5 (SPSS, IL, USA).

**Results**

The proximate composition and amino acids composition of the ingredients are tabulated in Tables 2 and 3. ADCs for dry matter, crude protein, and energy in the test ingredients are shown in Table 4. Results indicated that the ADCs for dry matter (75.1%-28.5%), crude protein (94.9%-64.7%), and energy (96.0%-57.6%) significantly affected by the composition of the test ingredients. Among plant protein products WF presented the highest ADCs for dry matter. However, no differences for ADCs of dry matter were observed among SBM, DSBM, CSM, PM, and CM. Among animal protein products, dry matter digestibility of PFFM, LFM and SHM was significantly lower than that of SDFM; however, no differences for ADCs of dry matter were observed between LFM and SHM.

<table>
<thead>
<tr>
<th>Test ingredients</th>
<th>Dry (%)</th>
<th>Crude protein (%)</th>
<th>Crude (%)</th>
<th>Gross (%)</th>
<th>Phosphorus (%)</th>
<th>Fiber (%)</th>
<th>Ash (%)</th>
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<tbody>
<tr>
<td>Steam dried fish meal&lt;sup&gt;a&lt;/sup&gt;</td>
<td>92.08</td>
<td>70.91</td>
<td>10.29</td>
<td>21.8</td>
<td>2.24</td>
<td>-</td>
<td>13.50</td>
</tr>
<tr>
<td>Peruvian FAO fish meal&lt;sup&gt;b&lt;/sup&gt;</td>
<td>93.89</td>
<td>69.44</td>
<td>8.89</td>
<td>20.5</td>
<td>2.88</td>
<td>-</td>
<td>15.29</td>
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<tr>
<td>Local fish meal&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>69.77</td>
<td>10.0</td>
<td>19.7</td>
<td>2.69</td>
<td>-</td>
<td>17.79</td>
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<td>Soybean meal&lt;sup&gt;a&lt;/sup&gt;</td>
<td>90.93</td>
<td>50.01</td>
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<td>0.75</td>
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<td>Dehulled soybean meal&lt;sup&gt;c&lt;/sup&gt;</td>
<td>91.20</td>
<td>51.42</td>
<td>1.39</td>
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<td>0.69</td>
<td>3.3</td>
<td>6.06</td>
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<td>Shrimp head meal&lt;sup&gt;a&lt;/sup&gt;</td>
<td>90.15</td>
<td>42.08</td>
<td>1.01</td>
<td>12.8</td>
<td>1.28</td>
<td>5.0</td>
<td>37.66</td>
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<td>Cottonseed meal&lt;sup&gt;c&lt;/sup&gt;</td>
<td>93.71</td>
<td>44.13</td>
<td>1.20</td>
<td>19.0</td>
<td>1.26</td>
<td>10.2</td>
<td>6.25</td>
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<td>Peanut meal&lt;sup&gt;b&lt;/sup&gt;</td>
<td>90.04</td>
<td>55.37</td>
<td>5.02</td>
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<td>0.89</td>
<td>6.0</td>
<td>5.01</td>
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<td>Wheat flour&lt;sup&gt;a&lt;/sup&gt;</td>
<td>90.88</td>
<td>18.28</td>
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<td>41.94</td>
<td>1.71</td>
<td>19.5</td>
<td>1.17</td>
<td>11.4</td>
<td>6.93</td>
</tr>
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<sup>a</sup> Yongsheng Feed Corporation Ltd, Binzhou, China  
<sup>b</sup> Jinhanshan Feed Corporation Ltd, Foshan, China  
<sup>c</sup> Libao Feed Corporation Ltd, Foshan, China

SDFM, steam dried fish meal; LFM, local fish meal; PFFM, Peruvian FAQ fishmeal; SHM, shrimp head meal; SBM, soybean meal; DSBM, dehulled soybean meal; PM, peanut meal; CSM, cottonseed meal; CM, canola meal; WF, wheat flour.
Table 3 Amino acid composition of test ingredients (% in dry matter)

<table>
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<tr>
<th>Amino acid</th>
<th>PFFM</th>
<th>SDFM</th>
<th>LFM</th>
<th>SHM</th>
<th>SBM</th>
<th>DSBM</th>
<th>CSM</th>
<th>PM</th>
<th>WF</th>
<th>CM</th>
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<td>Lys</td>
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<td>4.86</td>
<td>3.04</td>
<td>2.91</td>
<td>2.91</td>
<td>2.05</td>
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<td>2.31</td>
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<td>Phe</td>
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<td>2.11</td>
<td>2.34</td>
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<td>Met</td>
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<td>1.83</td>
<td>1.36</td>
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<td>0.85</td>
<td>0.70</td>
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<tr>
<td>Thr</td>
<td>2.48</td>
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<td>1.54</td>
<td>1.53</td>
<td>1.71</td>
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<td>Ile</td>
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<td>0.25</td>
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<td>4.59</td>
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<td>60.98</td>
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<td>45.54</td>
<td>44.18</td>
<td>45.51</td>
<td>10.99</td>
<td>35.73</td>
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</table>

SDFM, steam dried fish meal; LFM, local fish meal; PFFM, Peruvian FAQ fish meal; SHM, shrimp head meal; SBM, soybean meal; DSBM, dehulled soybean meal; PM, peanut meal; CSM, cottonseed meal; CM, canola meal; WF, wheat flour.

Table 4 Proximate composition of the reference and test diets (n=3, % dry matter)

<table>
<thead>
<tr>
<th>Components</th>
<th>Reference diet</th>
<th>Test diets (70% reference diet +30% test ingredients)</th>
</tr>
</thead>
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<td></td>
<td>PFFM</td>
<td>SDF</td>
</tr>
<tr>
<td>Dry matter</td>
<td>93.22</td>
<td>89.2</td>
</tr>
<tr>
<td>Crude protein</td>
<td>46.15</td>
<td>55.8</td>
</tr>
<tr>
<td>Crude lipid</td>
<td>7.41</td>
<td>8.61</td>
</tr>
<tr>
<td>Ash</td>
<td>11.34</td>
<td>12.6</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>1.27</td>
<td>1.85</td>
</tr>
<tr>
<td>Gross energy (kJg(^{-1}))</td>
<td>19.5</td>
<td>20.5</td>
</tr>
</tbody>
</table>

SDFM, steam dried fish meal; LFM, local fish meal; PFFM, Peruvian FAQ fish meal; SHM, shrimp head meal; SBM, soybean meal; DSBM, dehulled soybean meal; PM, peanut meal; CSM, cottonseed meal; CM, canola meal; WF, wheat flour.

Apparent digestibility coefficients for dry matter, crude protein, and energy in feedstuffs consumed by juvenile shrimp are presented in Table 5. Apparent energy digestibility coefficients for animal products that ranged between 76.0–96.0% were less variable than those for plant products that ranged between 57.6–85.1%. For crude protein, digestibility coefficient exceeding 90% was recorded for SDFM. Protein digestibility of WF was intermediate and no significantly different to either CM or CSM. SBM, DBSM and PM did not differed significantly in crude protein digestibility, nor did
Apparent digestibility of protein, energy, and amino acids in feed ingredients for *Litopenaeus vannamei*

PFFM, LFM and SHM. With few exceptions, ingredients that differed significantly in protein digestibility also differed significantly in energy digestibility.

The apparent amino acid availability coefficients of the test ingredients consumed by juvenile shrimp are presented in Table 6. For the animal source meals, the availability of amino acids in SDFM, SHM and LFM was higher than their availability in PFFM. Among all plant meals, the availability of amino acids in SBM was higher than in other plant meals. The availability of amino acids in WF was the lowest among the ingredients tested.

<table>
<thead>
<tr>
<th>Components</th>
<th>Dry matter</th>
<th>Crude protein</th>
<th>Gross energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference diet</td>
<td>69.0±0.92</td>
<td>91.4±0.50</td>
<td>84.5±1.00</td>
</tr>
<tr>
<td>PFFM</td>
<td>36.2±4.77abc</td>
<td>78.2±2.04def</td>
<td>78.7±3.55cde</td>
</tr>
<tr>
<td>SDFM</td>
<td>75.1±2.17c</td>
<td>94.9±0.19f</td>
<td>96.0±1.54f</td>
</tr>
<tr>
<td>LFM</td>
<td>55.2±2.05c</td>
<td>83.6±4.85c</td>
<td>86.9±2.42c</td>
</tr>
<tr>
<td>SHM</td>
<td>53.3±1.01bc</td>
<td>81.0±2.77c</td>
<td>76.0±2.28c</td>
</tr>
<tr>
<td>SBFM</td>
<td>30.2±4.40a</td>
<td>81.3±1.63c</td>
<td>66.2±0.71ab</td>
</tr>
<tr>
<td>DSBM</td>
<td>36.4±3.52a</td>
<td>82.2±2.04c</td>
<td>75.7±6.79cd</td>
</tr>
<tr>
<td>CSM</td>
<td>33.8±5.3a</td>
<td>73.4±1.75cd</td>
<td>78.2±0.30cd</td>
</tr>
<tr>
<td>PM</td>
<td>29.7±3.12a</td>
<td>78.6±0.44de</td>
<td>74.4±3.13bc</td>
</tr>
<tr>
<td>WF</td>
<td>61.8±3.98bc</td>
<td>64.7±0.35b</td>
<td>85.1±2.11de</td>
</tr>
<tr>
<td>CM</td>
<td>28.5±1.00bc</td>
<td>68.7±1.25bc</td>
<td>57.6±0.96a</td>
</tr>
</tbody>
</table>

SDFM, steam dried fish meal; LFM, local fish meal; PFFM, Peruvian FAQ fishmeal; SHM, shrimp head meal; SBM, soybean meal; DSBM, dehulled soybean meal; PM, peanut meal; CSM, cottonseed meal; CM, canola meal; WF, wheat flour.

Values are means ± SE (n=3 replicates per treatment). Means in the same column with the same superscript are not significantly different (P>0.05) from one another.

**Discussion**

Generally, the protein quality and its digestibility of dietary ingredients is the leading factor affecting aquaculture performances. In this study, the apparent protein digestibility of PFFM and LFM were significantly lower than those of SDFM, even though there was no significant difference in the component among these three kinds of feeds. The lower crude protein digestibility value for PFFM was possibly due to processing effects. Excessive heat can cause severe damage to protein quality (Soares et al., 1971). This is in agreement with Cowey et al. (1972) who reported that freeze-dried and low temperature dried (30°C) cod meal are almost identical in their essential amino acid content, yet they showed different growth rates in fish like plaice. Another possible cause may be due to the high lipid levels in PFFM. Lower protein digestibility in high-lipid feeds might be related to the formation of protein-and oxidized-fat complexes during drying (Ufodike and Matty, 1983; Anderson et al., 1995). The protein apparent digestibility of SDFM was 94.9%, a value that may be due to its well-balanced amino acid profile (Andrews and Page 1974). The disparity in the apparent protein digestibility determined between the studies could be due to the chemical composition of the ingredients, freshness of the raw material, the method of cooking, drying and storage.
Table 6 Apparent availability coefficients of amino acids in test ingredients consumed by juvenile *Litopenaeus vannamei*.

<table>
<thead>
<tr>
<th>Amino acids composition</th>
<th>Reference diet</th>
<th>Test ingredients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PFFM</td>
<td>SDFM</td>
</tr>
<tr>
<td>Lys</td>
<td>96.1±0.07</td>
<td>91.6±1.5e</td>
</tr>
<tr>
<td>Phe</td>
<td>94.9±0.03</td>
<td>84.8±1.8bc</td>
</tr>
<tr>
<td>Met</td>
<td>97.2±0.17</td>
<td>96.6±0.4df</td>
</tr>
<tr>
<td>Thr</td>
<td>94.2±0.09</td>
<td>90.0±1.3f</td>
</tr>
<tr>
<td>Ile</td>
<td>94.6±0.19</td>
<td>85.9±1.9bc</td>
</tr>
<tr>
<td>Leu</td>
<td>95.3±0.06</td>
<td>88.0±1.9bc</td>
</tr>
<tr>
<td>Val</td>
<td>93.4±0.09</td>
<td>84.4±2.1cd</td>
</tr>
<tr>
<td>His</td>
<td>95.1±0.18</td>
<td>87.4±2.2bc</td>
</tr>
<tr>
<td>Arg</td>
<td>97.0±0.10</td>
<td>91.5±1.2bc</td>
</tr>
<tr>
<td>Ser</td>
<td>95.9±0.38</td>
<td>92.6±3.0fg</td>
</tr>
<tr>
<td>Glu</td>
<td>96.0±0.13</td>
<td>88.8±1.6e</td>
</tr>
<tr>
<td>Pro</td>
<td>94.9±0.34</td>
<td>86.7±1.4ab</td>
</tr>
<tr>
<td>Gly</td>
<td>94.2±0.10</td>
<td>85.1±1.0bc</td>
</tr>
<tr>
<td>Ala</td>
<td>94.6±0.19</td>
<td>87.0±1.7cd</td>
</tr>
<tr>
<td>Cys</td>
<td>88.8±0.79</td>
<td>85.1±1.7de</td>
</tr>
<tr>
<td>Tyr</td>
<td>93.2±0.28</td>
<td>86.9±1.5ab</td>
</tr>
<tr>
<td>Asp</td>
<td>94.2±0.19</td>
<td>85.9±1.8g</td>
</tr>
</tbody>
</table>

SDFM, steam dried fish meal; LFM, local fish meal; PFFM, Peruvian FAQ fishmeal; SHM, shrimp head meal; SBM, soybean meal; DSBM, dehulled soybean meal; PM, peanut meal; CSM, cottonseed meal; CM, canola meal; WF, wheat flour.

Values are means ± SE (n=3 replicates per treatment). Means in the same column with the same superscript are not significantly different (P>0.05) from one another.

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and the length of storage. Although direct comparisons of derived digestibility values between experiments (and between different species) are fraught with danger, the overwhelming evidence is that SDFM was best digestible for L, vannamei.

Of the plant products tested, SBM was used because it is a cost-effective feed ingredient for many aquaculture animals (Storebakken et al., 2000) and its digestibility extensively studied in relation to various fish species. There is a broad range on the protein ADC (76–98%) (Glencross et al., 2005; Sugiura et al., 1998; Tibbetts et al., 2004; Kim et al., 2007), the value found here for L, vannamei (81.3%) was within this range. SBM, DSBM and PM were utilized significantly better than other plant ingredients with average protein ADC contents of 81.3%, 82.2% and 78.6% respectively. These values were close to, or equal to, those of PFFM, LFM and SHM 78.2%, 83.6% and 81.0%. This result indicated that these types of protein sources can be used effectively by L, vannamei. Increased use of these plant-protein supplements in L, vannamei diets will reduce feed cost and help reduce the dependence on fish meal as the primary protein source. Our findings suggest that substituting SBM into DSBM has a positive effect on the content of crude protein and fiber. Given that protein and energy digestibility of DSBM were not significantly different from SBM, the additional processing significantly increased the cost of the products without providing additional benefit on a price/digestible nutrient basis. The low-protein digestibility coefficients of CM may be due to known anti-nutritional components, such as glucosinolates, fiber, carbohydrate and phenolic constituents (Teskeredzic, et al., 1995).

The apparent digestibility values ranged from 28.5 % (CM) to 36.4% (DSBM) with the exception of WF (61.8%). By comparison, the DM apparent digestibility of animal feed ingredients was higher, especially for the SDFM (75.1%) and LFM (55.2%), which indicated that shrimp can better utilize the dry matter in animal products than that in plant product. This phenomenon was also found in previous studies (Sullivan and Reigh, 1995). The amount of ash in these ingredients appeared to be the main factor that reduced their digestibility. This can be attributed to their high-carbohydrate content and poor digestibility by L. vannamei as suggested also by others(Lee 2002; Zhou et al. 2004). The relatively higher dry matter apparent digestibility of WF (61.8%) could be explained by the more digestible starch compounds in the ingredient.

In aquatic animals, digestibility of plant products tends to be inversely related to their fiber content and in some species to starch content as well. Fiber contains virtually no digestible energy for monogastric animals while starch can be digested with varying degrees of efficiency, depending on the chemical composition of the starch and the digestive capability of the species to which it is fed (Brunson et al., 1997). Thus, apparent energy digestibility can vary widely among plant products, even among materials of similar proximate composition. From the data obtained in the present study with L, vannamei, energy was readily obtained from animal products and some plant products containing highly digestibility protein or starch. As the WF has AED value of over 85.0%, and can be used as energy sources for shrimps.

Besides the knowledge of nutrient and energy digestibility coefficients, an ingredient can only be used effectively when the digestibility of its amino acids (AA) is known. In the present study, SDFM had the highest ADCs average total AA, whereas the WF had the lowest. In addition, there were significant differences between digestibility coefficients of some of the essential amino acids within a protein source. Hence, amino acid availabilities cannot be estimated from the apparent digestibility coefficients of crude protein, as also reported by Lupatsch et al. (1997), Wilson et al. (1981), Masumoto et al. (1996), and De Silva et al. (2000). By contrast, these researchers observed that the amino acids availability tended to reflect protein digestibility coefficients of feed ingredients (Mu et al., 2000; Zhou et al., 2004). These results could have been related to interactions (associative effects) among ingredients or possible leaching losses from faeces prior to collection (Brunson, et al. 1997).

In conclusion, this study suggests that L, vannamei are able to efficiently digest animal protein in feeds and that local sources of FM and SHM can potentially substitute

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fish meal in diets for L, *vannamei*. Among the plant feed ingredients, only SBM, DSBM, and PM were well digested by L, *vannamei*, and can be considered as a partial dietary replacement of fish meal. A shown here, the use of individual amino acid availability values can improve the ability to formulate effective but cheaper diets for shrimp.

**Acknowledgements**

We thank J. Yang, S. Y. Zhou, X.J. Cui, L.G. Wang and J. Zhao for sample collection, and J.Y. He for sample analysis. The work was financially supported by the funds of Natural Science Foundation of Jiangsu Province (BK2012092), national modern industrial technology system of shrimp (nycytx-46), and team project of natural science foundation of Guangdong province (10351064001000000).

**References**


