Physicochemical properties of cowpea (Vigna unguiculata L. Walp.) meals and their apparent digestibility in white shrimp (Litopenaeus vannamei Boone).

Propiedades fisicoquímicas de harinas de frijol yorimón (Vigna unguiculata L. Walp.) y su digestibilidad aparente en camarón Litopenaeus vannamei Boone.

Martha Elisa Rivas-Vega1,3, Ofelia Rouzaud-Sandez2, María Guadalupe Salazar-García2, Josafat Marina Ezquerra-Brauer2, Ernesto Goytortúa-Bores1 & Roberto Civera-Cerecedo1*

2 Universidad de Sonora. Rosales y Transversal s/n, Hermosillo, Sonora, 83000, México.
3 Centro de Estudios Superiores del Estado de Sonora. Carretera a Huatabampo y Periférico Sur, Navojoa, Sonora, 85800, México. Autor para correspondencia: rcivera04@cibnor.mx

ABSTRACT

The effect of different feed processing methods on the physicochemical properties, and apparent digestibility of cowpea (Vigna unguiculata) meals as ingredients in diets for white shrimp (Litopenaeus vannamei) was investigated. Five experimental cowpea meals were prepared: whole raw (WRC), dehulled (DC), cooked (CC), germinated (GC) and extruded (EXC). The physicochemical properties of the meals were evaluated using differential scanning calorimetry. The meals were included at 15% in diets for L. vannamei (15.4 g) to determine firmness of pellets and in vivo digestibility of nutrients by using chromic oxide as inert marker. Six diets were evaluated: a control diet, and five diets containing the different cowpea meals. Transition enthalpy significantly decreased after thermal treatment, from 6.1 J/g in WRC to 1.4 J/g in CC, and disappeared in EXC. Firmness of pellets varied from 1.1 N in the EXC diet to 2.8 N in the WRC diet. A significant negative correlation between transition enthalpy and carbohydrate digestibility was found. Dry matter, protein, carbohydrate and lipid digestibility of cowpea meals significantly increased after germinating, cooking or extruding. It is concluded that germinated, cooked and extruded cowpea meals are highly digestible for shrimp and that enthalpy of transition is negatively correlated with the digestibility of carbohydrates.

Key words: Cowpea meals, digestibility, feedstuff, shrimp feeds.

RESUMEN

Se evaluó el efecto de diferentes procesos sobre las propiedades fisicoquímicas y digestibilidad aparente de la harina de frijol yorimón (Vigna unguiculata) como ingrediente en alimentos para camarón blanco (Litopenaeus vannamei). Se elaboraron cinco harinas de frijol yorimón: entero crudo (WRC), decorticado (DC), cocido (CC), germinado (GC) y extruido (EXC). Las características térmicas de las harinas fueron evaluadas usando calorimetría diferencial de barrido. Se elaboraron seis alimentos experimentales: un alimento control y cinco...
alimentos conteniendo 15 % de las diferentes harinas de frijol yorimón. A estos alimentos se le determinó firmeza y digestibilidad in vivo de nutrientes para L. vannamei (15.4 g) usando óxido de cromo como marcador inerte. La entalpía de transición decreció después del tratamiento térmico, de 6.1 J/g en la WRC a 1.4 J/g en la CC, y desapareció en la EXC. La firmeza de los alimentos varió de 1.1 N en el alimento con EXC a 2.8 N en el alimento con WRC. Se encontró una correlación significativa negativa entre la entalpía de transición y la digestibilidad de carbohidratos de la harina del frijol yorimón. La digestibilidad de materia seca, proteína, carbohidratos y lípidos de las harinas de frijol yorimón aumentó significativamente con el germinado, la cocción y la extrusión. En el presente estudio se concluye que las harinas de frijol yorimón germinado, cocido y extruido son altamente digeribles para camarón L. vannameí, y la entalpía de transición se correlaciona significativamente con la digestibilidad de los carbohidratos.

Palabras clave: Alimento camarón, digestibilidad, harinas frijol yorimón, ingredientes.

INTRODUCCIÓN

El desarrollo sostenible de la acuicultura favorece ingredientes que permitan la elaboración de alimentos balanceados y de bajo costo, de forma ecologica. Los ingredientes comestibles de la acuicultura incluyen carbohidratos, que son las principales fuentes de energía. Los carbohidratos provistos en forma de harinas de legumbres como frijol yorimón pueden mejorar la digestibilidad de ingredientes para camarón. El objetivo de este estudio fue determinar el efecto de diferentes procesos de preparación de fríojoles yorimón en la digestibilidad in vivo de nutrientes para Penaeus vannamei (15.4 g) usando óxido de cromo como marcador inerte. Se encontró una correlación significativa negativa entre la entalpía de transición y la digestibilidad de carbohidratos de la harina del frijol yorimón. La digestibilidad de materia seca, proteína, carbohidratos y lípidos aumentó significativamente con el germinado, la cocción y la extrusión. En el presente estudio se concluye que las harinas de frijol yorimón germinado, cocido y extruido son altamente digeribles para camarón L. vannameí, y la entalpía de transición se correlaciona significativamente con la digestibilidad de los carbohidratos.

Experimental cowpea meals. Cowpea beans (V. unguiculata) were obtained from Sierra de Alamos, Sonora, Mexico. Whole raw cowpea (WRC) was subjected to different processes as described by Rivas-Vega et al. (2006):

1) Dehulled (DC) in a Strong & Scott 17810MR, Chicago, IL, USA, dehulling machine;

2) Cooked (CC), by soaking beans in distilled water (1:10 cowpea: water (w/v)) during 105 minutes at room temperature, boiled for 20 minutes and dried in a convection oven at 40 °C for 24 hours;

3) Germinated (GC) on humid filter paper in a germination chamber (Biotronette Mark III, Lab-Line) at 33 °C and 50 % relative humidity for 3 days in complete darkness, then dried in a convection oven at 40 °C for 24 hours; and,

4) Extruded (EXC) in a single screw extruder (Brabender GmbH & Co., Duisburg, Germany) with temperature of 80 °C at entrance and of 180 °C at exit, using 1000-1200 kPa of pressure. Material was fed into the conditioner at a rate of 25 kg/h.

The different cowpea products obtained were milled in a pulverizer (PULVEX 200, México, D.F.), sifted through 250 μm mesh sieve, and stored at 4 °C until used.

Formulation and elaboration of diets. A control diet containing 34 % protein, 8 % lipids, and 1 % Cr₂O₃ (used as indirect marker for in vivo digestibility determinations) was formulated. Five experimental diets containing 84 % of the control diet, 15 % of cowpea test meals, and 1 % Cr₂O₃ were also formulated (Table 1). Prior to preparing the experimental diets, all ingredients were pulverized and sieved through a 250 μm mesh sieve. The dry ingredients of each diet were mixed thoroughly in a food mixer before a mixture of fish oil and soybean lecithin was added. Water was added at approximately 40 % of the total “as is” ingredient weight, and mixed. The resulting mixture was pressure
Table 1. Ingredient composition (g/100 g diet) and proximate composition (g/100 g dry matter, except moisture) of the diets used to determine in vivo digestibility of different cowpea meals in L. vannamei juveniles.

<table>
<thead>
<tr>
<th>Diet</th>
<th>Control</th>
<th>Whole raw</th>
<th>Dehulled</th>
<th>Cooked</th>
<th>Germinated</th>
<th>Extruded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Raw Cowpea&lt;sup&gt;1&lt;/sup&gt;</td>
<td>00.00</td>
<td>15.00</td>
<td>00.00</td>
<td>00.00</td>
<td>00.00</td>
<td>00.00</td>
</tr>
<tr>
<td>Dehulled&lt;sup&gt;1&lt;/sup&gt;</td>
<td>00.00</td>
<td>00.00</td>
<td>15.00</td>
<td>00.00</td>
<td>00.00</td>
<td>00.00</td>
</tr>
<tr>
<td>Cooked&lt;sup&gt;1&lt;/sup&gt;</td>
<td>00.00</td>
<td>00.00</td>
<td>00.00</td>
<td>15.00</td>
<td>00.00</td>
<td>00.00</td>
</tr>
<tr>
<td>Germinated&lt;sup&gt;1&lt;/sup&gt;</td>
<td>00.00</td>
<td>00.00</td>
<td>00.00</td>
<td>00.00</td>
<td>15.00</td>
<td>00.00</td>
</tr>
<tr>
<td>Extruded&lt;sup&gt;1&lt;/sup&gt;</td>
<td>00.00</td>
<td>00.00</td>
<td>00.00</td>
<td>00.00</td>
<td>00.00</td>
<td>15.00</td>
</tr>
<tr>
<td>Wheat flour&lt;sup&gt;2&lt;/sup&gt;</td>
<td>35.93</td>
<td>30.49</td>
<td>30.49</td>
<td>30.49</td>
<td>30.49</td>
<td>30.49</td>
</tr>
<tr>
<td>Soybean meal&lt;sup&gt;2&lt;/sup&gt;</td>
<td>25.00</td>
<td>21.21</td>
<td>21.21</td>
<td>21.21</td>
<td>21.21</td>
<td>21.21</td>
</tr>
<tr>
<td>Fish meal (sardine)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>20.00</td>
<td>16.97</td>
<td>16.97</td>
<td>16.97</td>
<td>16.97</td>
<td>16.97</td>
</tr>
<tr>
<td>Kelp meal&lt;sup&gt;3&lt;/sup&gt;</td>
<td>4.00</td>
<td>3.39</td>
<td>3.39</td>
<td>3.39</td>
<td>3.39</td>
<td>3.39</td>
</tr>
<tr>
<td>Corn gluten&lt;sup&gt;3&lt;/sup&gt;</td>
<td>3.77</td>
<td>3.20</td>
<td>3.20</td>
<td>3.20</td>
<td>3.20</td>
<td>3.20</td>
</tr>
<tr>
<td>Cod liver oil&lt;sup&gt;4&lt;/sup&gt;</td>
<td>3.00</td>
<td>2.55</td>
<td>2.55</td>
<td>2.55</td>
<td>2.55</td>
<td>2.55</td>
</tr>
<tr>
<td>Soy Lecitin&lt;sup&gt;5&lt;/sup&gt;</td>
<td>3.00</td>
<td>2.55</td>
<td>2.55</td>
<td>2.55</td>
<td>2.55</td>
<td>2.55</td>
</tr>
<tr>
<td>Vitamin premix&lt;sup&gt;6&lt;/sup&gt;</td>
<td>1.80</td>
<td>1.53</td>
<td>1.53</td>
<td>1.53</td>
<td>1.53</td>
<td>1.53</td>
</tr>
<tr>
<td>Dibasic sodium phosphate&lt;sup&gt;7&lt;/sup&gt;</td>
<td>1.20</td>
<td>1.02</td>
<td>1.02</td>
<td>1.02</td>
<td>1.02</td>
<td>1.02</td>
</tr>
<tr>
<td>Cholesterol&lt;sup&gt;8&lt;/sup&gt;</td>
<td>0.50</td>
<td>0.42</td>
<td>0.42</td>
<td>0.42</td>
<td>0.42</td>
<td>0.42</td>
</tr>
<tr>
<td>Mineral premix&lt;sup&gt;9&lt;/sup&gt;</td>
<td>0.50</td>
<td>0.42</td>
<td>0.42</td>
<td>0.42</td>
<td>0.42</td>
<td>0.42</td>
</tr>
<tr>
<td>Choline chloride 62 %&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.20</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>Vitamin C&lt;sup&gt;10&lt;/sup&gt;</td>
<td>0.090</td>
<td>0.076</td>
<td>0.076</td>
<td>0.076</td>
<td>0.076</td>
<td>0.076</td>
</tr>
<tr>
<td>BHT&lt;sup&gt;11&lt;/sup&gt;</td>
<td>0.004</td>
<td>0.0034</td>
<td>0.0034</td>
<td>0.0034</td>
<td>0.0034</td>
<td>0.0034</td>
</tr>
<tr>
<td>Chromic oxide&lt;sup&gt;12&lt;/sup&gt;</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Proximate composition<sup>13</sup>

<table>
<thead>
<tr>
<th></th>
<th>Moisture</th>
<th>Crude protein</th>
<th>Ether extract</th>
<th>Crude fiber</th>
<th>Ash</th>
<th>N.F.E.</th>
<th>Energy (kJ/g)</th>
<th>Water stability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole raw</td>
<td>6.6±0.05</td>
<td>32.9±0.16</td>
<td>8.5±0.04</td>
<td>1.7±0.21</td>
<td>15.9±0.05</td>
<td>47.4</td>
<td>19.4</td>
<td>94.2±1.1</td>
</tr>
<tr>
<td>Dehulled</td>
<td>6.0±0.02</td>
<td>32.5±0.01</td>
<td>7.2±0.05</td>
<td>1.6±0.36</td>
<td>14.6±0.05</td>
<td>38.2</td>
<td>17.4</td>
<td>90.7±0.9</td>
</tr>
<tr>
<td>Cooked</td>
<td>7.3±0.11</td>
<td>32.2±0.39</td>
<td>7.1±0.08</td>
<td>1.0±0.03</td>
<td>15.7±0.09</td>
<td>36.7</td>
<td>17.2</td>
<td>91.8±0.2</td>
</tr>
<tr>
<td>Germinated</td>
<td>6.9±0.12</td>
<td>32.8±0.30</td>
<td>7.4±0.03</td>
<td>1.5±0.28</td>
<td>15.2±0.12</td>
<td>36.2</td>
<td>17.1</td>
<td>92.2±2.2</td>
</tr>
<tr>
<td>Extruded</td>
<td>6.3±0.14</td>
<td>33.4±0.42</td>
<td>7.0±0.01</td>
<td>0.9±0.01</td>
<td>14.9±0.15</td>
<td>37.4</td>
<td>17.3</td>
<td>91.0±1.5</td>
</tr>
<tr>
<td>Wheat flour</td>
<td>6.7±0.10</td>
<td>33.5±0.26</td>
<td>6.8±0.10</td>
<td>1.9±0.08</td>
<td>15.3±0.06</td>
<td>35.7</td>
<td>17.1</td>
<td>92.6±1.1</td>
</tr>
</tbody>
</table>

1 Prepared in the laboratory from cowpea Vigna unguiculata, Sierra de Álamos, Sonora, México.
2 Promotora Industrial Acuasistemas, S.A. de C.V., La Paz, B.C.S., México.
3 Gluten y Almidones Industriales S.A. de C.V., México, D.F.,
4 Farmacia Paris, S.A. de C.V. México, D.F.,
5 ODONAJI, Distribuidora de Alimentos Naturales y Nutricionales S.A. de C.V. México, D.F.
6 Composition of the vitamin premix (g/kg premix): Vit. A (20,000 UI/g) 5.6, D<sub>3</sub> (850,000 UI/g) 0.001, DL-α-tocopheryl acetate (250 UI/g) 2.5, Menadione 2.2, Thiamin-HCl 0.6, Riboflavin 3.3, Pyridoxine-HCl 1.1, DL-Ca-Pantothenate 5.6, nicotinic acid 5.6, Biotin 0.1, Inositol 5.6, B<sub>12</sub> 0.002, folic acid 0.2, alpha-celulose 961.4.
7 SIGMA Cat No. S-0876. SIGMA-ALDRICH Chemical Company, St. Louis, MO, USA.
8 SIGMA Cat. No. C-8503. SIGMA-ALDRICH Chemical Company, St. Louis, MO, USA.
9 Composition of the mineral premix (g/100 g premix): CoCl<sub>2</sub> 0.004, CuSO<sub>4</sub>.5H<sub>2</sub>O 0.25, FeSO<sub>4</sub>.7H<sub>2</sub>O 4, MgSO<sub>4</sub>.7H<sub>2</sub>O 28.389, MnSO<sub>4</sub>.H<sub>2</sub>O 0.65, KI 0.067, Na<sub>2</sub>SeO<sub>3</sub> 0.01, ZnSO<sub>4</sub>.7H<sub>2</sub>O 13.193, alpha-celulose 53.428.
10 Stay C (35% active agent). Roche, México, D.F.
11 Butylated hydroxytoluene, ICN Cat. No.101162. Aurora, Ohio, USA.
12 Aldrich Cat. No. 20,216-9. SIGMA-ALDRICH Chemical Company, St. Louis, MO, USA.
13 Values are means of three replicates ± SD.
14 Nitrogen Free Extract.
15 Calculated from energetic values of nutrients (kJ/g): protein 23.4, lipid 39.8, carbohydrates 17.2 (Tacon, 1987).
pelleted using a meat grinder and a 2 mm die. The pellets were dried in a convection oven at 45 °C for 12 hours.

**Differential Scanning Calorimetry (DSC).** The phase transition temperatures and enthalpies of cowpea meals were measured using a differential scanning calorimeter 1020 Series DSC7 (Perkin-Elmer, Norwalk, Connecticut). The instrument was calibrated using Indium and Zinc as standards. The cowpea meals were weighed (5-15 mg, wet weight) and distilled water was added (200 % w/w) in DSC hermetic pans (PE No. 0319-0218); three replicates by treatment were used. Determinations of transition temperatures were run at a heating rate of 10 °C/min, from 26 °C to 145 °C. An empty pan was used as a reference. Enthalpy change (∆H, J/g) was determined, measuring the area under the curve of the thermogram using the 1022 Series Thermal Analysis software from Perkin Elmer. The maximum transition temperature of the peaks was recorded.

**Apparent digestibility trial.** Juvenile white shrimp *L. vannamei* with a weight of 15.4 g ± 0.9 g were stocked in 60 L rectangular tanks (58 × 48 × 25 cm) at a density of 5 shrimp/tank. Three replicate tanks were randomly assigned for each diet. Shrimps were maintained in filtered seawater at 27.1 ± 0.01 °C for 300 °C until a red ring of the peaks was recorded.

Apparent Digestibility Coefficient (ADC) of nutrients (%)

\[
\text{ADC Nutrient} = \left( \frac{\text{Nutrient in faeces}}{\text{Nutrient in feed}} \right) \times 100
\]

Where:

\[
\text{ADC Nutrient} = 100 - 100 \times \left( \frac{\text{Nutrient in faeces}}{\text{Nutrient in feed}} \right)
\]

**Statistical analysis.** Apparent Digestibility Coefficients of ingredients were analyzed using non-parametric Kruskal Wallis test to determine significant differences among treatments, and a Newman-Keuls multiple range test was used to identify differences among means. Calorimetric data were analyzed using one-way ANOVA to determine significant differences among treatments, and a Tukey’s multiple range test was used to identify differences among means. A regression analysis of Apparent Digestibility Coefficients of carbohydrates and transition enthalpy of cowpea meals was conducted. All statistical analyses were performed at 0.05 significance level using STATISTICA™ 7.0 (StatSoft, Inc., Tulsa, OK, USA).

**RESULTS AND DISCUSSION**

Calorimetric methods have been applied to study the structure and phase transitions of starch in pure and complex food systems. The presence of ordered chain domains and the interactions between starch and food constituents can be probed by DSC, trough changes in the heat flow, while the sample is heated over a range of temperatures (Biliaderis, 1992). This is a thermal-analytical technique in which the difference in the amount of heat required to increase the temperature of a sample and reference are measured as a function of temperature (Biliaderis et al., 1980). Thermograms of cowpea meals obtained by differential scanning calorimetry (Figure 1) showed a first peak or transition, commonly known as starch gelatinization. Whole raw (WRC), dehulled (DC) and germinated (GC) cowpea meals showed a maximum temperature of the first transition between 81-82 °C. Transition temperature of cooked (CC) cowpea meal was 61.8 °C. Transition temperature in extruded cowpea (EC) meal was not detected (Table 2). The results coincide with Henshaw et al., (2003); they found a maximal temperature of the first transi-
Cowpea meals properties and digestibility in shrimp.

transition between 78.1-82.2 °C for 12 cowpea varieties. However, *Phaseolus vulgaris* and *Lens esculenta* show transition temperature of 74.9 °C and 63.8 °C, respectively, without heat treatment (Yáñez-Farias et al., 1997). It has been suggested that differences in transition temperature of starches are due to differences in shape and size of starch granules, amylose content and internal molecular arrangement of starch fractions within the granule (Yáñez-Farias et al., 1997).

Cowpea meal is a heterogeneous system, where the major macromolecules (starch and protein) contribute to the heat changes. Enthalpy may be better designated as overall transition enthalpy encompassing all heat changes associated with components in the system capable of thermal transition (Henshaw et al., 2003). Enthalpic changes of the first transition significantly diminished after food processing from 6.1 J/g for raw cowpea to 4.3 J/g for dehulled cowpea, and 2.5 J/g for germinated cowpea. Considering that starch is the major component of cowpea meal, this is explained as the energy needed (fusion enthalpy) to break the intermolecular bonds in starch granules to achieve gelatinization is lower, indicating that the native starch content has been reduced after dehulling and germination, since there is a smaller number of intermolecular connections to be broken in the starch chains. During dehulling, the speed of the abrasive disks increases the system temperature, causing changes in the cowpea components. During the germination process conducted under conditions of high humidity, amylases act on the starch components (Mayer & Poljakoff-Mayber, 1982). This process reduces the number of intermolecular bonds in starch, causing a reduction in the energy required to transition.

The first transition temperature detected in cooked cowpea beans was approximately 20 °C lower than that of raw cowpea beans. This can be interpreted as gel fusion in the crystallized starch (Biliaderis, 1992). Once the gelatinized starch cools down, structural changes in the gel causes crystallization. The change of enthalpy of this process was 1.4 J/g. Extruded cowpea beans transition temperature was not detected since the starch was completely gelatinized under the conditions of temperature and humidity used during the extrusion.

The endothermic transition temperatures of second peak in the samples of dehulled and germinated cowpea were 93.7 and 95 °C, respectively. The amylose molecule coils in a helix form, and it can form occlusion complexes between lipids and carbohydrates. Applying a temperature gradient modifies the starch molecular structure, thus allowing the formation of occlusion complexes. Osman-Ismail (1972) found that formation of occlusion complexes occur at a range of temperature between 23 to 85 °C, and temperature at which these occlusion complexes occur depends on the type of starch and of volatile compounds. In this study, the formation of the occlusion complex detected in the thermal analysis could have occurred after increase of system temperature during the dehulling process (Russell & Juliano, 1983).
No significant differences in temperature, salinity and dissolved oxygen were found among treatments in the digestibility trial. Temperature was maintained within the optimum range of 25 to 28 °C (Lee & Wickins, 1992; Clifford, 1994). Dissolved oxygen was maintained above the lower limit (3 mg/L) recommended for shrimp culture (Boyd, 1989; Fast & Lester, 1992).

The dry matter digestibility of the raw whole cowpea meal was 76.5 %, and significantly increased after cooking, germination and extrusion processes (104.7, 103.1 and 97.1 %, respectively) (Table 3). Protein and lipid digestibility of the cowpea meals also increased by cooking, germination and extrusion. The digestibility of carbohydrates increased after germinating, dehulling, cooking and extruding. Assuming that the trypsin inhibitor in cow pea decreases digestibility then the increase in apparent digestibility due to cooking and extrusion may be due to decreased trypsin inhibitor activity, and also to the loss of protein and starch original configuration, which facilitates the enzymatic hydrolysis occurring during shrimp digestive processes. Ghavidel & Prakash (2007) found a significant negative correlation between in vitro starch digestibility and antinutritional factors of germinated and dehulled cowpea meals. Rivas-Vega et al. (2006) found that trypsin inhibitor activity reduced after cooking and extruding cowpea beans. On the other hand, dry matter, protein and carbohydrate digestibility of diets containing these meals was improved (Rivas-Vega et al., 2006).

Some studies have reported that starch gelatinization improves digestibility of carbohydrate by L. vannamei (Davis & Arnold, 1993; Cousin et al., 1996). In the present study, a significant correlation ($R^2 = 0.93$) between the enthalpy change of the first transition and in vivo carbohydrate digestibility of cowpea meals was observed (Figure 2). These results provide important information to consider Differential Scanning Calorimetry as a rapid

### Table 2. Transition enthalpy and transition temperature of cowpea (Vigna unguiculata) meals obtained by different food processing methods.

<table>
<thead>
<tr>
<th>Meal</th>
<th>Transition enthalpy ($\text{J/}g$)</th>
<th>Transition temperature ($^\circ\text{C}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole raw</td>
<td>6.16±0.64$^c$</td>
<td>81.59±0.78$^p$</td>
</tr>
<tr>
<td>Dehulled</td>
<td>4.32±0.20$^b$</td>
<td>81.42±0.07$^p$</td>
</tr>
<tr>
<td>Cooked</td>
<td>1.42±0.74$^a$</td>
<td>61.86±1.59$^a$</td>
</tr>
<tr>
<td>Germinated</td>
<td>2.50±0.65$^a$</td>
<td>82.95±0.66$^b$</td>
</tr>
<tr>
<td>Extruded</td>
<td>ND$^2$</td>
<td>ND</td>
</tr>
</tbody>
</table>

$^1$ Values are means of three replicates ± SD. $^2$ Not Detected. Values within the same column with different superscripts are significantly different ($p < 0.05$).

![Figure 2. Relationship between carbohydrate digestibility and transition enthalpy of cowpea meals ($p<0.05$).](image-url)
Cowpea meals properties and digestibility in shrimp.

Table 3. Apparent digestibility coefficients (% ± SD) for dry matter, crude protein, carbohydrate, lipid and energy of cowpea (Vigna unguiculata) meals obtained by different processes.

<table>
<thead>
<tr>
<th>Meal</th>
<th>Dry matter (%)</th>
<th>Crude protein (%)</th>
<th>Carbohydrates (%)</th>
<th>Lipids (%)</th>
<th>Energy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole raw</td>
<td>76.5±8.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>86.5±2.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72.8±4.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>74.6±4.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>76.7</td>
</tr>
<tr>
<td>Dehulled</td>
<td>56.1±1.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>73.3±2.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>94.1±4.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>76.7±4.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>93.9</td>
</tr>
<tr>
<td>Cooked</td>
<td>104.7±2.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>105.5±2.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>99.0±3.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>106.3±3.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>107.2</td>
</tr>
<tr>
<td>Germinated</td>
<td>103.1±7.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>102.6±4.8&lt;sup&gt;c&lt;/sup&gt;</td>
<td>92.5±3.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>103.7±5.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>101.6</td>
</tr>
<tr>
<td>Extruded</td>
<td>97.1±5.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>103.4±3.8&lt;sup&gt;c&lt;/sup&gt;</td>
<td>98.2±1.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>113.0±4.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>101.8</td>
</tr>
</tbody>
</table>

<sup>1</sup> Values are means of three replicates ± SD. Values within the same column with different superscripts are significantly different (p<0.05).

and effective method to predict carbohydrate digestibility of ingredients used in diets for shrimps. Another advantage of this method is that the thermal characteristics of the samples can be evaluated in situ. It is important to highlight that our results were obtained from the same legume species using different technological processes, but it is important to evaluate the Differential Scanning Calorimetry on different sources of carbohydrates, and to test the sensibility of this method to predict in vivo digestibility.

The apparent digestibility coefficients of dehulled, cooked, germinated and extruded cowpea meals, in some cases, were greater than 100%. Physiologically this cannot be explained, but similar results have been reported in different studies on the digestibility of plant ingredients by shrimp (Brunson et al., 1997, Divakaran et al., 2000; Cruz-Suárez et al., 2001). Some authors attribute it to an interaction between the ingredients of the feed. Divakaran et al. (2000) suggested that dietary inclusion levels of soybean meal (35 and 46.3%) can affect the passage of chromium oxide through the digestive tract of *L. vannamei*, since they found a significant interaction (p<0.05) between these two inclusion levels. Brunson et al. (1997) obtained values of 101, 110 and 107% for dry matter, protein and energy digestibility of wheat gluten for *P. setiferus*, and attributed it to possible interactions between the nutrients of the ingredients.

Firmness of pellets, determined after 30 minutes of soaking, varied from 1.1 N for the EXC diet to 2.8 N for the WRC diet (Figure 3). Although pellet texture is an important factor for feed

![Figure 3. Firmness of cowpea diets for Litopenaeus vannamei used in the digestibility assay. Different superscripts on the bars indicate significant differences (p<0.05).](image)
consumption by shrimp (Cruz-Suárez, 1998), very little information exists about this property. Cerécer-Cota et al. (2004) reported that feed firmness is negatively correlated to feed consumption in L. vannamei. Feed consumption was not measured in our study, but no significant correlation between pellet firmness and in vivo digestibility of cowpea meals in L. vannamei was found.

CONCLUSIONS

Cowpea meals were highly digestible for L. vannamei. Carbohydrate digestibility increased after germinating, dehulling, cooking and extruding. Temperature and enthalpy of the first transition of cowpea meals decreased after food processing, especially after thermal processing. The carbohydrate digestibility could reasonably be predicted based on the first transition enthalpy.

ACKNOWLEDGMENTS

This work was possible thanks to financial support of CONACYT (Grant No. 129253 to Martha Rivas), CIBNOR (project AC 1.22) and SAGARPA (project 2003-CO2-149). We thank Rosalina Ramírez (Universidad de Sonora) for comments and suggestions to the manuscript, Juan Manuel Vargas López (Universidad de Sonora) for extruding cowpea, and Ana María Ibarra and José Luis Ramírez (Shrimp Genetic Improvement Program-CIBNOR) for providing the experimental organisms.

REFERENCES


Ghavide, R. A. & J. Prakash. 2007. The impact of germination and dehulling on nutrient, antinutrients, in vitro iron and calcium bioavail-
Cowpea meals properties and digestibility in shrimp.


Recibido: 2 abril de 2008.

Aceptado: 1 de marzo de 2009.